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DATA ON THE THICKNESS AND CHARACTER OF CERTAIN SEDIMENTARY SERIES IN OHIO

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INTRODUCTION

The total thickness of the sedimentary rocks in Ohio as measured on the outcrop is a little more than 5,000 feet. As the various series pass under cover away from the outcrop changes in thickness occur which can be determined by a study of data derived from well borings. Based on rather limited data of this type, various estimates have been made from time to time of the thickening of certain sedimentary series to the eastward in Ohio along designated lines.[2] However, as deep well drilling has continued the quantity of available data has increased and a comparative study of some 8,500 well records now on file in the office of the Geological Survey of Ohio has yielded the results set forth in the following pages. Such data lack much that is to be desired in the way of scientific accuracy and detail, but nevertheless the close correspondence in essential fact of data derived from many sources argues for considerable accuracy in its major features. It is believed that the results of such a study will be of interest to geologists and to all who are engaged in the search for oil and gas.

CLASSIFICATION OF THE SEDIMENTARY ROCKS OF OHIO

The following table gives a brief classification of the sedimentary strata in Ohio and includes the name and character

[1]Published by permission of Mr. Wilber Stout, Director, Geological Survey of Ohio.

[2]Hills, T. M. Some Estimates of the Thickness of the Sedimentary Rocks of Ohio. *Jour. Geol.*, Vol. XXVIII (1920), pp. 84–86. Also various reports of the Geological Survey of Ohio.

of the chief subdivisions, the thickness on the outcrop, and the terms in general use by the well driller. Many of the details of the classification have been omitted. The thickness of the different groups, series, formations, or members appearing in this table have been compiled from various detailed reports. The correlations with surface outcrops of the various strata recognized in drilling are in part the conclusions of the writer, and in part the opinions of others which have appeared in various publications of the Geological Survey of Ohio.

TABLE OF CLASSIFICATION

System	Group, Series, or Formation	General Character	Thickness on Outcrop (Feet)	Drillers Terms
Permian	Greene	Many kinds	405	
	Washington	Many kinds	221	
	Monongahela	Many kinds	144	
		Sandstone, Sewickley	20	Goose Run sand
		Several kinds	84	
Pennsylvanian	Allegheny	Many kinds	82	
		Sandstone, Connellsville	20	Mitchell sand
		Several kinds	7	
		Sandstone, Morgantown	0–30	Wolf Creek or Milner sand
		Many kinds	100	
		Sandstone, Cow Run	30	Macksburg 140-foot or First Cow Run sand
		Many kinds	40	
		Sandstone, Buffalo	23	Buell Run sand
		Many kinds	106	
		Sandstone, Upper Freeport	33	Macksburg 300-foot or Dunkard sand
		Many kinds	117	
		Sandstone, Clarion	10	Macksburg 500-foot sand
		Many kinds	34	
	Pottsville	Many kinds	154	
		Sandstone, Massillon	24	Second Cow Run or Salt sand
		Many kinds	93	
		Sandstone, Sharon	10	Macksburg 800-foot, Maxton, or Lower Salt sand

TABLE OF CLASSIFICATION—(*Continued*)

System	Group Series, or Formation	General Character	Thickness on Outcrop (Feet)	Drillers Terms
Mississippian	Maxville	Limestone	0 to 20	Big Lime of southeastern Ohio
	Logan	Sandstone and shale	0 to 200	Keener sand
	Cuyahoga	Sandstone, Black Hand	175 to 600	Big Injun and Squaw sand
		Shale		
		Sandstone, Buena Vista		Hamden, Welsh Stray, or Weir sand
		Shale		
	Sunbury	Shale, black	5 to 30	Coffee shale
	Berea	Sandstone	0 to 200	Berea sand
	Bedford	Shale, gray and red	60 to 90	
		Sandstone, local		Second Berea sand
Devonian	Ohio	Shale, black, Cleveland	300 to 700	Little Cinnamon and Big Cinnamon
		Shale, gray, Chagrin		
		Shale, black, Huron		
		Shale, gray, Olentangy		
	Delaware	Limestone	30 to 70	
	Columbus	Limestone	60 to 110	
	Detroit River	Dolomite	0 to 200	
	Sylvania	Sandstone	0 to 20	Big Lime (The Oriskany sand, salt beds and Newburg sand occur in this series)
Silurian	Bass Island	Dolomite and shale	0 to 300	
	Niagara	Dolomite	25 to 300	
	Alger	Shale	10 to 100	
	Dayton	Limestone	2 to 12	Shell or Little Lime
	Brassfield	Limestone	10 to 50	Shell or Little Lime
Ordovician	Richmond	Shale, red and gray	215 to 265	
		Sandstone, red and white		Clinton sand
		Shale, red		Medina
		Shale, pink and red		
		Shale, bluish gray, with thin limestone		
	Maysville	Shale and thin limestone	140 to 240	
	Eden	Shale, blue, with thin limestone	180 to 250	
	Trenton*	Limestone	40 to 200	Trenton
	Lexington	Limestone, cherty	290 to 315	
	Highbridge	Limestone and dolomite with some shale	250 to 420	
	St. Peter	Sandstone, calcareous		St. Peter sand. Horizon of Blue Lick Water

*The series below the Trenton do not outcrop in Ohio.

THE SEDIMENTARY SERIES BELOW THE ST. PETER SAND

A number of holes have been drilled in the western half of Ohio to varying depths below the St. Peter sand, but only a few have actually reached the underlying crystalline complex. In a test hole which was sunk near Findlay, Hancock County, in 1912 and which reached the granite at a depth of 2,980 feet, 780 feet of sediments were penetrated below the St. Peter sand. A second test near Woodville, Sandusky County, encountered 730 feet of sediments below the St. Peter sand and reached a depth of 2,822 feet. The drill has also reached the crystallines near Tiffin, Seneca County, at a depth of about 2,900 feet, but the details of this record are not available. A number of years ago a deep test was drilled near Waverly, Pike County, in which the St. Peter sand was reached at 2,825 feet and fragments of igneous rock were reported to have been secured at a depth of 3,320 feet.[3]

The deepest test in the western half of Ohio was drilled near South Charleston, Clark County, in 1926–1927. The drill reached a depth of 4,647.5 feet, but it failed to pass through the sedimentaries. The Blue Lick water sand or St. Peter was encountered at a depth of 2,055 feet, and it is therefore underlain at this place by at least 2,592 feet of sediments or over three times the thickness occurring below the St. Peter at Findlay or Woodville.

It is highly probable that the upper surface of the crystalline rocks upon which the sediments were deposited was very irregular and in view of the small number of holes which have been drilled through the entire series in Ohio, any prediction as to its depth outside of the Findlay-Woodville-Tiffin area is somewhat hazardous.

THE TRENTON-ST. PETER SERIES

The series from the top of the Trenton to the St. Peter sand is composed of limestone and dolomite with some shale in the lower part which is usually of a greenish color. The upper part of this series is exposed along the banks of the Ohio River at Cincinnati, but the lower part consisting of the Lexington and Highbridge series does not outcrop in this state, although it comes to the surface farther south in Kentucky.

[3]Bassler, R. S. The Stratigraphy of a Deep Well at Waverly, Ohio. *Am. Jour. Science*, 3rd. Ser., Vol. 31 (1911), pp. 19–24.

Below this limestone, dolomite, and shale series is a bed of white calcareous sand or sandy limestone which contains large quantities of strong brine known as the Blue Lick water. This water-bearing sand is the St. Peter sand of Orton[4] and it is generally known among well drillers by that name. The St. Peter sand does not outcrop in Ohio or Kentucky, but it has been reached at a number of places by the drill. At least 80 holes have been sunk to this horizon in Ohio, nearly all of which are located in the western two-thirds of the state and chiefly east of the belt of Trenton production.

By a comparison of well records it has been found that the St. Peter sand occurs at distances below the top of the Trenton, which vary from 435 to 885 feet. The series is thin over an elongated area extending from Columbus southwest to western Pike and eastern Highland counties and also along the western edge of the state in western Butler, Preble, and Darke counties. A second area of reduced thickness extends from Allen County northeast to Erie County. This latter area seems to be continuous with a similar region of thinning extending in a northeastern direction across southwestern Ontario.[5] The series thickens, however, to the northwest in the direction of Michigan and to the southeast in eastern Ohio. The conditions of thickening and thinning of the Trenton-St. Peter series as indicated by well records are shown in Figure 1.

THE TRENTON-BIG LIME SERIES

The Trenton-Big Lime series outcrops in southwestern Ohio where it forms the surface rocks in Hamilton, Butler, Warren, Clermont, and Brown counties and in portions of adjacent counties to the east and north. Beyond this outcrop area the series extends beneath younger beds throughout eastern and northern Ohio. It has been penetrated by the drill at many places in the western half of the state, but it is probably best known to the driller in the producing fields in the northwestern part where hundreds of wells have been sunk to the Trenton limestone. The thickness of the Trenton-Big Lime series as disclosed by well records varies from 660 to 1,950 feet. The thinnest areas are found in Williams and Defiance counties, from where this series thickens irregularly to the east and

[4]Orton, Edward. *Geol. Survey, Ohio*, Vol. VI (1888), p. 7.

[5]See map of southwestern Ontario by R. B. Harkness, Ontario Gas Commissioner.

southeast, while the greatest thickness is encountered along the eastern line of Trenton holes. Thus, this series measures

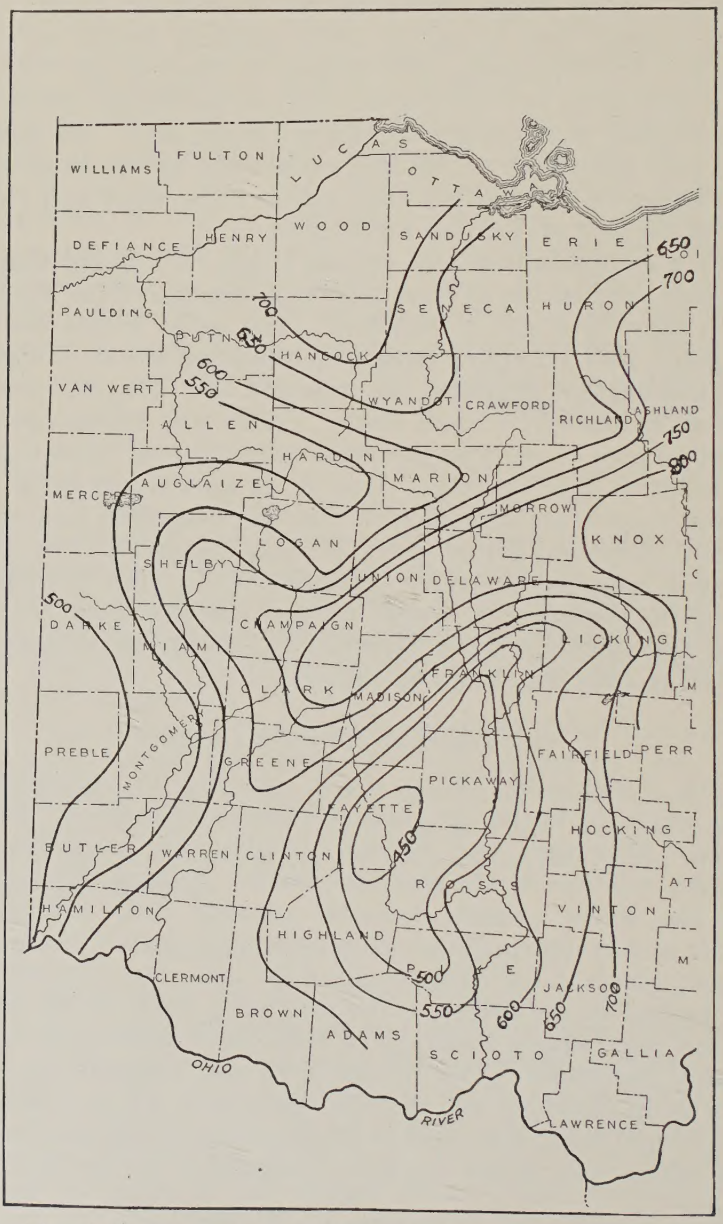

FIG. 1. Map of the western part of Ohio showing isopachs of the series extending from the St. Peter (Blue Lick water) horizon to the top of the Trenton limestone.

1,950 feet in Rome Township, Ashtabula County; 1,700 feet in Brunswick Township, Medina County; 1,360 feet in Jackson Township, Ashland County; 1,560 feet in Hanover Township, Licking County; and 1,400 feet in Jefferson Township, Jackson County. Southeast of this line the drill has not penetrated to a level much below the horizon of the Clinton sand.

The Trenton-Big Lime series consists of shales and thin limestones comprising the Eden, Maysville, Richmond, Brassfield, Dayton, and Alger beds. Throughout all parts of Ohio where this series has been penetrated, a limestone which varies in thickness from 5 to 75 feet and which is known to the driller as the Shell or Little Lime, is present near the top of the series and corresponds in position to the Brassfield and Dayton limestones of surface outcrops. In parts of the belt of Clinton sand production two "shells" are present, separated by a thin bed of shale. The Shell or Little Lime is separated from the base of the Big Lime by a bed of shale which, as pointed out by Orton,[6] is 15 feet or less in thickness in the west-central part of Ohio. This shale increases somewhat in thickness to the east and southeast, however, for in the belt of Clinton sand production it ranges from 75 feet in Lorain County to 250 feet in Lawrence and southern Jackson counties. The material is generally of a greenish gray color, but red shales are common on this horizon in southern Ohio. The Shell is more or less closely underlain with red shale and the red and white Clinton sand.

A second conspicuous feature of the series is a bed of black and brown shale which overlies the Trenton and which often yields small flows of gas. This shale which forms the lower part of the Eden group is known as the Utica shale.[7] It is thin in southwestern Ohio, but it increases in thickness rapidly to the north, northwest, and northeast. The Utica shale has a thickness of about 35 feet in southern Butler County, 200 feet at Dayton in Montgomery County, 300 feet at Urbana in Champaign County, and apparently reaches its maximum thickness of 350 feet in Logan and Hardin counties. It thins slightly to the north, east, and west from Logan and Hardin counties, for it measures 290 feet at Van Wert, 300 feet at Napoleon, 275 feet at Bowling Green, 225 feet in southwestern

[6]Orton, Edward. *Geol. Survey, Ohio*, Vol. VI (1888), p. 13.
[7]Orton, Edward. *Geol. Survey, Ohio*, Vol. VI (1888), p. 8.

Ottawa County, and 285 feet near Tiffin. The Utica shale thickens again in the vicinity of Sandusky, where it measures

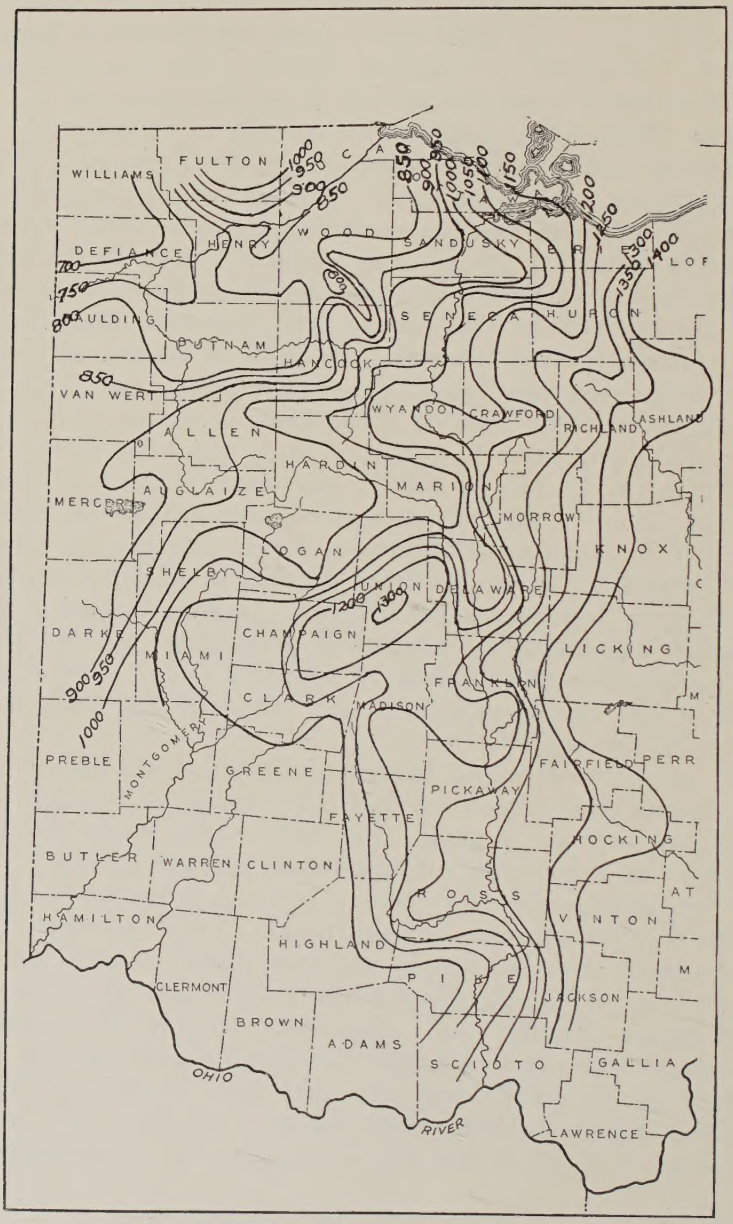

FIG. 2. Map of the western part of Ohio showing isopachs of the series extending from the Trenton Limestone to the base of the Big Lime.

about 335 feet. The thickness of the Trenton-Big Lime series in the western half of Ohio is shown in Fig. 2.

THE BIG LIME SERIES

The Big Lime series is well known to the driller, as a part or all of this group is penetrated in wells sunk to the Trenton or Clinton sands. This series forms the surface rocks in the Trenton field of northwestern Ohio and the surface exposures extend eastward to a line drawn from Sandusky Bay south through Delaware, Columbus, Greenfield, and Bainbridge and then southward to the Ohio River through eastern Adams County. East of this line the Big Lime dips beneath beds of younger age.

The thinnest part of the Big Lime as recorded in well records is found in Scioto and Pike counties where it measures about 300 feet. It thickens rapidly to the east and northeast, however, for it reaches its maximum development in Ohio along the eastern edge of the state from Columbiana County south to Washington County. From central Columbiana County this series thins again to the north in the direction of Conneaut. The greatest thicknesses yet recorded in this state are 1,987 feet in the Reamer well located in West Township, Columbiana County, and 1,841 feet in the Knowlton well in Independence Township, Washington County.

Stratigraphically the Big Lime includes the limestone and dolomite from the base of the thick Devonian shale to the base of the Niagara dolomite and comprises the Delaware and Columbus limestones, the Detroit River and Bass Island dolomites, and the Niagara dolomites as classified from surface exposures. The increase in thickness of the Big Lime series to the east in Ohio is due in part to the increase in thickness of some of the formations comprising it, and in part to the presence of other formations under cover which pinch out to the west before the outcrops are reached. Thus the Devonian limestones consisting of the Columbus and Delaware formations have a combined thickness on the outcrop of about 130 feet. Under cover the Oriskany sand which lies at the base of the Devonian limestone is found at depths below the top of the Big Lime of 110 to 160 feet in Guernsey County, 200 to 290 feet in Ashtabula County, 235 feet in Island Creek Township, Jefferson County, and 225 feet in Independence Township, Washington County.

In northeastern Ohio beds of rock salt with some shale and

dolomite, all of which probably represent the Salina group, are present in the Big Lime below the Oriskany sand horizon.

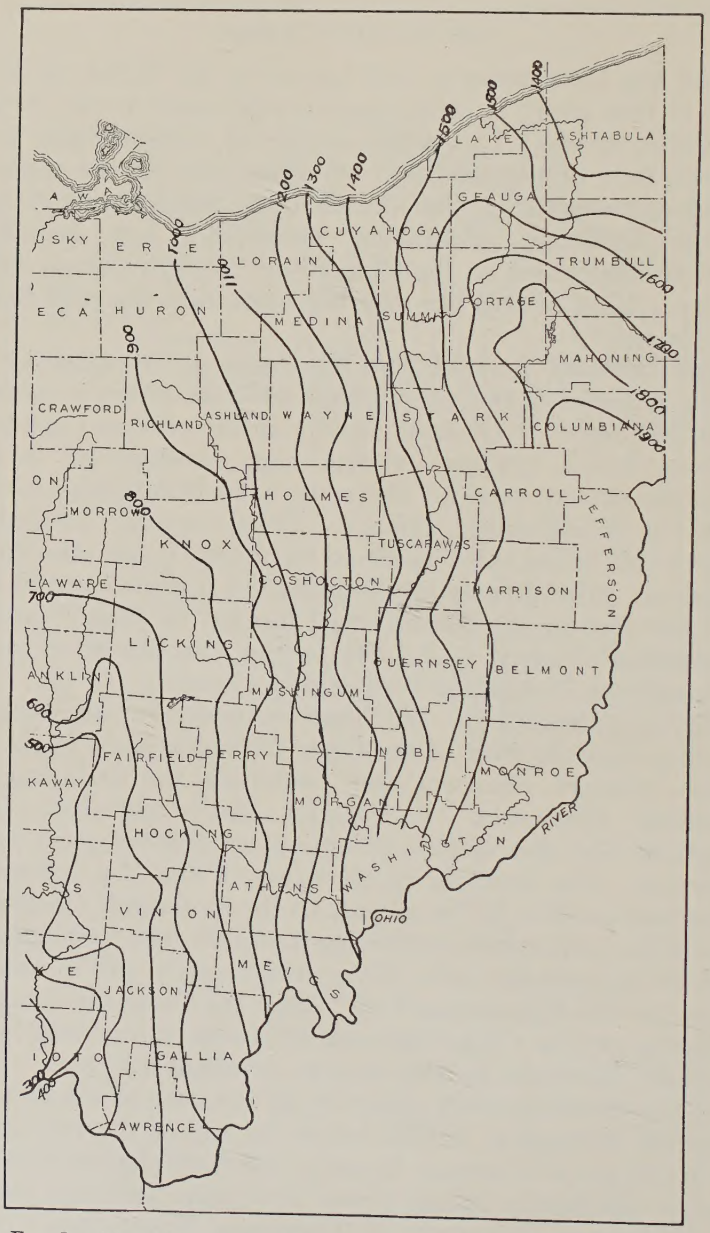

FIG. 3. Map of the eastern part of Ohio showing isopachs of the Big Lime series.

These beds in Ashtabula County approach 600 feet in thickness. This series thins to the west and southwest, however, the salt pinches out, and the dolomite and gypsum are not represented in the outcrops in west-central Ohio and their correlation with exposures in northern Ohio is uncertain.

Dolomite extends from the Salina to the base of the Big Lime. The widespread occurrence of a strong flow of brine about 150 to 300 feet above the base of the Big Lime suggests a persistent horizon of high porosity such as the upper surface of the Niagara dolomite. If this flow of brine comes from a definite stratigraphic horizon, there is little evidence for believing that the part of the Big Lime below it thickens much to the east in Ohio. As indicated from the foregoing discussion, the thickening of the Big Lime to the east is believed to occur chiefly in its middle portion. Greater detail within the Big Lime is impossible without a careful and extended study of drill cuttings. The thickness of the Big Lime series in different parts of the eastern half of Ohio is shown in Fig. 3.

THE BIG LIME-BEREA SERIES

The interval from the Big Lime to the Berea sand consists for the most part of black, brown, bluish gray, and red shales comprising the Ohio shale and Bedford shale formations. These shales outcrop over a belt of territory varying from two to twenty miles in width, extending from eastern Adams County northward to Erie County and then eastward along the shore of Lake Erie to the Pennsylvania line. The shales have a thickness on the outcrop in Adams County of about 340 feet, but they thicken irregularly to the north along the outcrop, reaching a depth of about 550 feet in Erie County. Eastward from Erie County the expansion is marked for near Cortland, Trumbull County, the thickness is about 2,300 feet.

Under cover the Big Lime-Berea series also shows a great expansion in thickness to the east. Along an east-west line from Pike Township, Knox County, to New Cumberland, Hancock County, West Virginia, the rate of expansion is about 28.9 feet per mile, while along a similar east-west line from Newark, Ohio, to Wheeling, West Virginia, this shale series increases in thickness to the east at the rate of about 33 feet per mile. From western Guernsey County to Wheeling the rate of increase is about 40 feet per mile. The expansion along a third east-west line from western Hocking County to eastern

Washington County is about 34 feet per mile to the east. The two greatest thicknesses yet encountered in tests drilled in

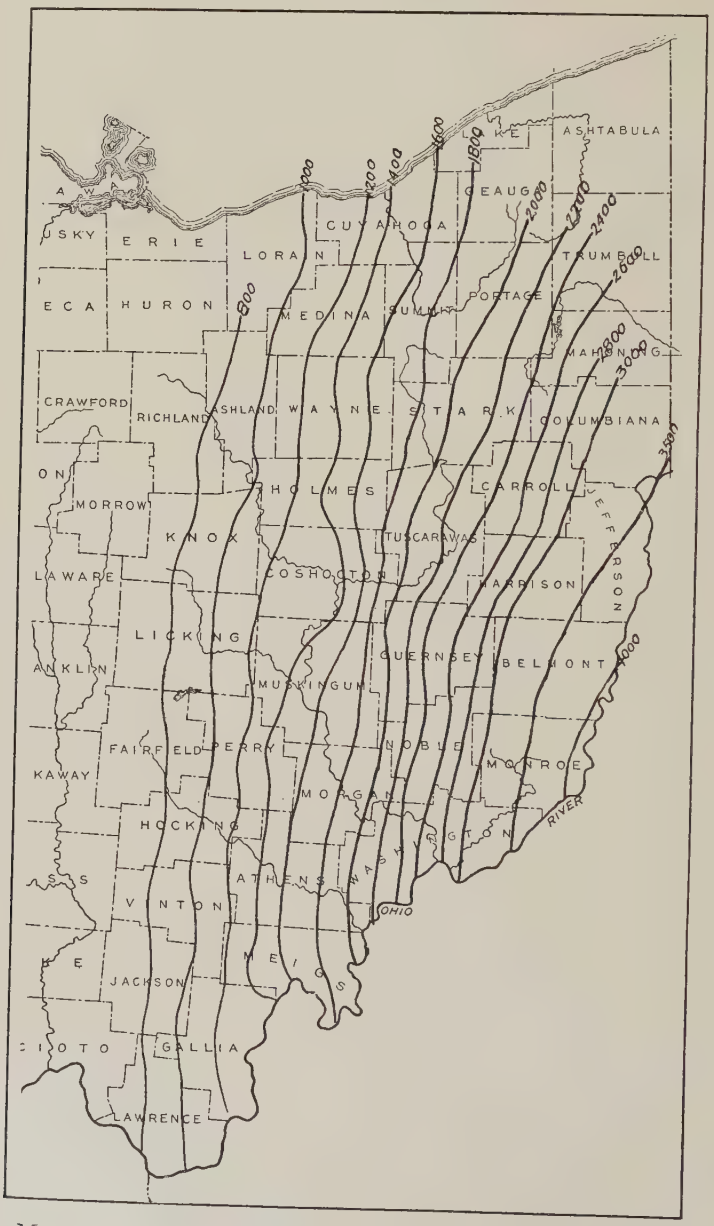

FIG. 4. Map of the eastern part of Ohio showing isopachs of the series extending from the top of the Big Lime to the base of the Berea Sand.

Ohio are 3,427 feet in Section 26, Island Creek Township, Jefferson County, and 3,341 feet in Section 10, Independence Township, Washington County.

The Ohio shale in northern Ohio is generally subdivided into three parts: a basal black shale or Huron, a middle gray shale or Chagrin, and an upper black shale or Cleveland member. This three-fold subdivision is not generally applied to the outcrops in central and southern Ohio although bluish-gray shale somewhat similar lithologically to the Chagrin is present in the middle portion in both regions and gives a three-phase character to the formation. Beneath the lower black shale of the Ohio formation and extending to the top of the Big Lime, there is another bed of blue shale which is persistent on the outcrop in central Ohio and which is found at many places in southern Ohio. This is the Olentangy formation of various reports on the geology of Ohio, but it is considered by the writer to be a phase of the Ohio formation.[8]

East of the belt of outcrops, black, brown and blue shales are encountered by the drill in all wells which have penetrated far below the Berea sand. West of a line from central Stark to central Lawrence counties the Big Lime is immediately overlain by material which is variously described as white or gray shale. This light material has a thickness of about 300 feet in western Stark County, 175 feet in western Muskingum County, and about 110 feet in western Lawrence County. It thins to the west and northwest of this line and at places it can be traced close to the outcrop. The stratigraphic position of this light shale suggests that it represents the eastern continuation of the so-called Olentangy shale of surface outcrops. This bed increases in thickness east of the line from central Stark to central Lawrence counties, but it is separated from the Big Lime by a wedge of black or brown shale which thickens to the east. In the deep well drilled on the Jones farm in Warren Township, Belmont County, the Big Lime is immediately overlain by 200 feet of black shale representing this wedge, above which occurs the gray shale; while in the test drilled in Island Creek Township, Jefferson County, the Big Lime is overlain by 400 feet of black shale with 775 feet of light shale above it.

Overlying the light shale which in the western part of the

[8]Lamborn, R. E. The Olentangy Shale of Southern Ohio. *Jour. Geol.*, Vol. XXXV (1927), pp. 708–722.

field forms the base of the Ohio shale there is a bed of black or brown shale which is generally known to the driller as the Cinnamon. Over large areas in eastern Ohio the Cinnamon is divided into two parts by a thin bed of blue or gray shale. The upper and thinner portion is called the Little Cinnamon, while the lower and thicker portion is known among the drillers as the Big Cinnamon. Showings of gas are of widespread occurrence in both of the cinnamon shales and the commercial production of shale gas in Lawrence County is apparently derived from these beds. The thickness of the Cinnamon shale along the first line of Clinton production from Jackson County to Lorain County varies irregularly from 300 to 400 feet. It increases in thickness somewhat to the southeast, however, for in general it measures 450 to 550 feet along a zone from western Noble County to western Columbiana County. The black Ohio shale of outcrops in central and southern Ohio is believed to represent the western continuation of the Cinnamon shale of the driller.

The shale from the Cinnamon to the base of the Berea sand is the most variable element in the Big Lime-Berea series, as it expands rapidly to the east in Ohio and as it is composed of a wide variety of materials. Along a north-south line from central Vinton County to central Ashland County this shale varies from 350 to 450 feet in thickness. It expands rapidly to the east, however, for it attains a thickness of 780 feet in northeastern Gallia County, 800 feet or more in central Athens County, 1,150 feet in central Guernsey County, and 1,400 feet or more in eastern Tuscarawas, western Carroll, and western Columbiana counties. In the deep test drilled in Island Creek Township, Jefferson County, in 1931 the shale between the Cinnamon and the Berea sand was found to have a thickness of 1,667 feet.

Red shale and thin sandstone are conspicuous elements in the shale series between the Cinnamon and the Berea. The red shale which for the most part is found less than 75 feet below the Berea sand is correlative with the red shale of the Bedford formation of surface outcrops. Sandstone is present close below the red shale and 20 to 60 feet below the Berea sand at some localities in western Medina and eastern Lorain counties. The position of this sandstone suggests that it represents the Euclid member of the Bedford formation. Sandstone occupying a similar position with respect to the

Berea is likewise found at many localities in southern Ohio. Through eastern Gallia, Meigs, Athens, eastern Morgan, and southern Muskingum counties a productive sandstone known as the Second Berea sand is present 15 to 75 feet below the Berea, from which it is separated at many places by red shale. This sandstone is likewise believed to be Bedford in age. Little detail can be derived from the series extending from the position of the Second Berea sand to the Cinnamon shale. Gray shale predominates in this interval, although red and pink shales are reported in the northeastern part of the state. The great array of productive sands below the Berea in West Virginia and western Pennsylvania belong in this series, but they either pinch out to the west or become so thin in eastern Ohio that they are generally described by the driller as "shells" and can not be correlated with accuracy. A notable exception, however, occurs in the presence of a thin sand of rather wide distribution which is found some 300 to 400 feet below the Berea sand.

THE MISSISSIPPIAN SERIES ABOVE THE BEREA SANDSTONE

The Mississippian series above the Berea sandstone outcrops over a broad belt extending from Scioto and eastern Adams counties on the south to Medina, Lorain, and southeastern Erie counties on the north and then eastward over a somewhat narrower belt embracing portions of Summit, Cuyahoga, Geauga, Trumbull, and southern Ashtabula counties. From the region of outcrop the series slopes to the southeast beneath the Pennsylvanian and Permian strata which constitute the surface beds in the southeastern third of the state. The most conspicuous formation above the Berea sand which can be followed under cover by well records is the Maxville limestone, the youngest formation of the Mississippian system in Ohio. The Maxville limestone apparently remains as an unbroken sheet over Monroe, southern Belmont, and eastern Noble counties where it varies from 25 to 200 feet in thickness. North, west and southwest of this area the limestone is patchy in distribution, for at many places it has been entirely removed by erosion occurring at the end of the Mississippian period and preceding the deposition of the Pennsylvanian sediments. Enough limestone remnants remain, however, to mark the contact of the systems over large areas and to permit the

determination of the thickness of the Mississippian strata above the Berea with some degree of accuracy.

Where the Maxville limestone has been removed other criteria for determining the position of the contact must be applied. White sands are relatively rare in the outcrops of Mississippian rocks but are of common occurrence in the lower part of the Pennsylvanian. White sands, therefore, found close above the Berea sand and accompanied by reduced intervals from the Berea to known horizons in the Pennsylvanian are considered as representing the basal portion of the Pennsylvanian.

The thickness of the Mississippian strata above the Berea is apparently greatest along the western outcrop from southern Hocking County northward to Ashland and Wayne counties. In Hocking County the thickness of this series varies from 750 to 850 feet; in southern Licking and southeastern Ashland counties it is about 700 feet; and in Wayne County the maximum thickness measures 870 feet.[9] From east-central Ohio the series thins somewhat to the southeast, but the most notable reduction in thickness is from the south and west toward eastern Stark, northern Columbiana, and southern Mahoning counties, where the basal beds of the Pennsylvanian lie less than 100 feet above the Berea. The range in thickness of the Mississippian series above the Berea in many counties in southeastern Ohio as determined from well records is as follows:

Athens County	550 to 650 feet
Belmont County	550 to 760 feet
Columbiana County (southern)	200 to 250 feet
Coshocton County	500 to 560 feet
Guernsey County	500 to 700 feet
Jefferson County (southern)	525 to 730 feet
Meigs County	450 to 600 feet
Monroe County	575 to 700 feet
Muskingum County	650 to 700 feet
Noble County	550 to 600 feet
Stark County (central)	300 to 350 feet
Vinton County	550 to 600 feet
Washington County	500 to 640 feet

The Maxville limestone is not known from well records north of an east-west line along the northern boundary of Harrison County and it has apparently been removed by erosion over large areas south of this line. It is also generally wanting on the outcrop except for small scattered exposures

[9]Conrey, G. W. *Geol. Survey Ohio*, Fourth Series, Bull. 24 (1921), pp. 49–50.

extending from western Muskingum County to northern Jackson County. The figures given above for the thickness of the series along the outcrop and in the northeastern part of the state apply to the clastic portion only, while in southeastern Ohio these figures include the remnants of the Maxville limestone.

The lower 300 to 400 feet of the Mississippian series above the Berea sand consists for the most part of bluish-gray and black shales, while sandstone is a conspicuous element in the upper half. Immediately overlying the Berea sand there is a thin bed of black shale known as "coffee" shale among the drillers, which represents the continuation under cover of the Sunbury shale. This black shale, which is very persistent, varies from 14 to 60 feet. The changes in thickness, however, are local in nature as no directional expansion is evident from a comparison of well records.

At many places in eastern and southeastern Ohio a sandy zone or "shell" is found from 65 to 100 feet above the Berea sand. This "shell" becomes a well developed sand in parts of Monroe County where it reaches a thickness of 175 feet and is called the Welsh Stray or Weir Sand. A thin sand at the same horizon is present in Jackson County where it is called the Hamden sand, and in Columbiana County where it is known as the Stray sand. The stratigraphic position of this sand suggests that it is correlative with the Buena Vista member of the Cuyahoga formation of surface outcrops.

Over much of southeastern Ohio sandstones form an important element in the 200 to 300 feet of strata immediately underlying the horizon of the Maxville limestone. These sandstones which are correlative with the Black Hand and Logan sandstones of surface outcrops, comprise the Squaw, Big Injun, and Keener sands of the driller. The Squaw sand, which lies at the base of this series, is relatively unimportant as it is thin and irregular in its occurrence. The top of this sandstone series is represented by the Keener sand, which rarely exceeds 60 feet in thickness, where it is best represented in Monroe and Belmont counties. The Big Injun sand, which lies between the Keener and Squaw sands, is the thickest and best known. From a comparative study of well records it appears that the Big Injun sand is well developed over two areas which are separated by a region of thin sandstone and shale. The first area of good sandstone development extends from southern Vinton County to southern Richland and

Ashland counties and lies west of a line passing through southeastern Vinton, eastern Athens, southeastern Perry, western Muskingum, western Coshocton, and western Holmes counties. In this area the sand is quite variable in thickness, but it shows no common directional expansion. Thicknesses of 300 feet or more occur in eastern Knox, western Muskingum, central Hocking, and eastern Vinton counties. The second area lies east of a line extending from central Meigs County through eastern Muskingum and eastern Wayne counties and includes eastern Meigs, Washington, Monroe, eastern Noble, Belmont, Guernsey, southern Jefferson, Harrison, western Carroll, Tuscarawas, western Stark, and eastern Wayne counties. In this portion of the field the Big Injun likewise shows great variation in thickness over small areas, but apparently reaches its best development over Monroe, Belmont, and southern Jefferson counties, where it measures as much as 300 feet.

Separating the two regions where the Big Injun sand is well expressed there is an elongated area including western Wayne, central Holmes, central Coshocton, east central Muskingum, Morgan, and eastern Athens counties in which the Big Injun sand is either wanting or is less than 50 feet in thickness. Apparently the thick sandstones found both to the east and west give way over this elongated area to thin sandstones and shales.

THE BEREA-PITTSBURGH COAL SERIES

In both the Permian and Pennsylvanian systems the horizons which can be correlated over large areas are generally wanting as most of the beds either lack continuity, want definite determinable characteristics, or are too thin to be recognized by the driller. The Pittsburgh coal is a notable exception. In southeastern Gallia County the Berea sand lies about 1,800 to 1,900 feet below this coal; in eastern Athens County the interval is 1,380 to 1,480 feet; while in eastern Muskingum County the distance is 1,480 to 1,520 feet. The Pittsburgh coal occurs 1,600 to 1,660 feet above the Berea sand in eastern Noble, southern Monroe, and southeastern Belmont counties. The interval decreases to the north along the Ohio River valley, however, for in central Jefferson County is measures 1,400 to 1,460 feet. When the horizon of the Pittsburgh coal is projected north and northwest beyond its outcrop into Columbiana County, the interval to the Berea is

found to be about 1,170 feet in Knox Township, about 1,200 feet in southern Madison Township near Wellsville, and about 1,240 feet near East Palestine in Unity Township. The decrease in this interval to the north, which is most rapid in northern Jefferson and Columbiana counties, is due to the removal by erosion of many feet of Mississippian sediments before the deposition of the Pennsylvanian beds.

SUMMARY AND CONCLUSIONS

From the foregoing discussion it is apparent that the St. Peter-Trenton series, the Trenton-Big Lime series, the Big Lime series, and the Big Lime-Berea series increase in thickness to the eastward in Ohio. This eastward expansion is due in part to the thickening of outcropping formations and in part to the presence under cover of certain beds which according to correlations based on a study of well records are not represented on the outcrop. Notable examples occur in the Clinton sand and overlying red and gray shales which have not been recognized on the outcrop. Either these beds never extended into the region of outcrop or they were removed by erosion before the deposition of the Brassfield (Shell) limestone. In the Big Lime series the salt beds with the associated gypsum and shale are not found to be represented in the outcrops in northern Ohio. A similar condition is present in the Big Lime-Berea series where beds of shale are present under cover both at the bottom and in the upper part of the series, neither of which are represented in surface outcrops of central and southern Ohio.

Of the various series above the St. Peter sand which have been described, the greatest thickening to the eastward occurs in the Big Lime and the overlying shales below the Berea sand. These series have their maximum combined thickness of about 5,900 feet in eastern Monroe and southern Belmont counties where the greatest depth of Permian is found. Adding 1,650 feet, the interval from the Berea sand to the Pittsburgh coal, and 870 feet, the combined thickness of the Monongahela and Permian strata, it is apparent that the series above the base of the Big Lime has a maximum thickness of about 8,420 feet. The series from the St. Peter sand to the base of the Big Lime likewise thickens to the eastward, but so many local variations occur in the western half of Ohio that the projection of any rate of increase eastward is somewhat hazardous. We believe

it safe to conclude, however, that the series above the St. Peter sand in eastern Monroe County has a thickness of 12,000 to 13,000 feet. Insufficient data prevents any conclusion as to the thickness of the sedimentary series below the St. Peter sand in eastern Ohio.

Radio and the Stars

This book, to quote the author, "is written to bring together recent conspicuous developments in astronomy and its related fields which may suggest a more intimate relationship between man and his cosmic environment than has perhaps been generally supposed." Beginning with the setting in space of the earth with its single satellite, the author considers its various motions, then discusses the observed evidence that latitude does not appear to remain fixed, and that the latitude of a place varies from time to time. This would tend to show that the earth is not absolutely rigid. The cause of the variations is possibly the attraction of the moon which makes our ocean tides and our relatively unsuspected earth tides. Time observations by radio show that such stations as the Naval Observatory, Washington, D. C., and the Royal Observatory, Greenwich, England, vary in their distance one from the other by as much as 63 feet. Again the moon is blamed. Whether or not the earth could lend itself to such bending leads to a consideration of the great value of the sun in our human affairs and then to the relation of sun-spots to the magnetism of the earth. The relation is close and the magnetic storms seem to be started in or by sun-spot activity. The magnetic storms effect radio reception, hence sun-spots effect radio, apparently by ionizing the upper atmosphere in the Kennelly-Heaviside layer, which reflects back our radio signals. The daily lowering and rising of this layer is the cause of night reception being better than day reception. Other agencies which influence the ionization of the night sky are considered. Going farther into space Cosmic clouds, clouds of obscuring matter, are encountered. Did they cause glaciation in the past? Geologists feel otherwise for the most part. Following Cosmic clouds are considered cosmic rays, those very penetrating rays which seem to come from outside of our own system. With a consideration of Cosmecology, a sort of astronomic ecology, Dr. Stetson concludes his book.

This is a most absorbing book for the non-astronomer, physicist, or geologist, as well as the professional astronomer, because it explains with just enough detail for clearness many of the phenomena, theories and ideas which concern the earth, radio and the stars. We compliment Dr. Stetson on the handling of so much complex material in such a delightful manner.—Willard Berry.

Earth, Radio and the Stars, by H. T. Stetson; xviii + 336 pp. New York, Whittlesey House (McGraw-Hill Book Co.), 1934.

On Understanding Mechanics

As is set forth in the preface, this book is a text to be used in a very elementary course in mechanics. Mathematics has been reduced to a very minimum, using only here and there the simplest algebraic relations. In the reviewer's opinion the book might be useful in a course in high-school physics or in a college course for beginners who have had no course in high-school physics. For use in high-school courses it would seem especially suitable for collateral reading.

—Harold H. Nielsen.

Mechanics for Beginners, by F. Barraclough and E. J. Holmyard; viii + 214 pp. Toronto, J. M. Dent & Sons.

DRAINAGE HISTORY OF NORTH CENTRAL OHIO

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University of New Hampshire

INTRODUCTION

Incident to a study of the glacial geology of the region in and around the re-entrant angle in the glacial boundary in northeast central Ohio, observations on present and past drainage lines were made in Crawford, Richland, Ashland, Wayne, Morrow, Knox, Holmes, and Coshocton counties. Examination shows, as noted by earlier workers, that many of the present streams flow from low land through higher land; that some large streams flow in small valleys; that some large valleys have no streams; and that, in fact, the present drainage system is a "patch-work" system of streams and valleys of very different sizes and characteristics. As an outgrowth of recent studies of glacial boundaries in the region, the present writer will attempt to show that the position of some of the narrow gorge-like valleys is obviously related to the position of the last Wisconsin ice edge, that some valleys, gorge-like but wider than those referred to the Wisconsin ice margin, are clearly related to the position of the Illinoian ice border, and that still other valleys which are very much wider than those of Illinoian age, but whose streams cross divides through cols and are therefore deranged, have had their courses governed by an early, pre-Illinoian, ice sheet. It is the belief of the present writer that most abandoned valleys, commonly referred to as "preglacial" are only "pre-last glacial" or "pre-Illinoian," rather than "pre-Pleistocene." In fact, the pre-Pleistocene valleys are now so modified that in most cases their location can be only inferred from the pre-Preistocene divides, still well preserved, which indicate ancient drainage basins and which afford clues to approximate locations of the Pliocene streams.

RELIEF AND PHYSIOGRAPHIC DIVISIONS[1]

The region varies from an almost flat plain 950 to 1,100

[1]This brief summary of the physiographic features is given here to aid in making more clear the discussion of drainage history. Detailed study of the geomorphology of the area here discussed and of territory to the north and south is now in progress and the results will be reported in another paper.

feet in elevation in the western part to a maturely dissected plateau 1,200 to 1,500 feet in elevation with a relief of 400 feet in the central and eastern part. A small part of the region, the lower, western part, falls within the Till Plains section of the Central Lowland province as arranged by Fenneman.[2] Most of the area, the central and eastern part, which

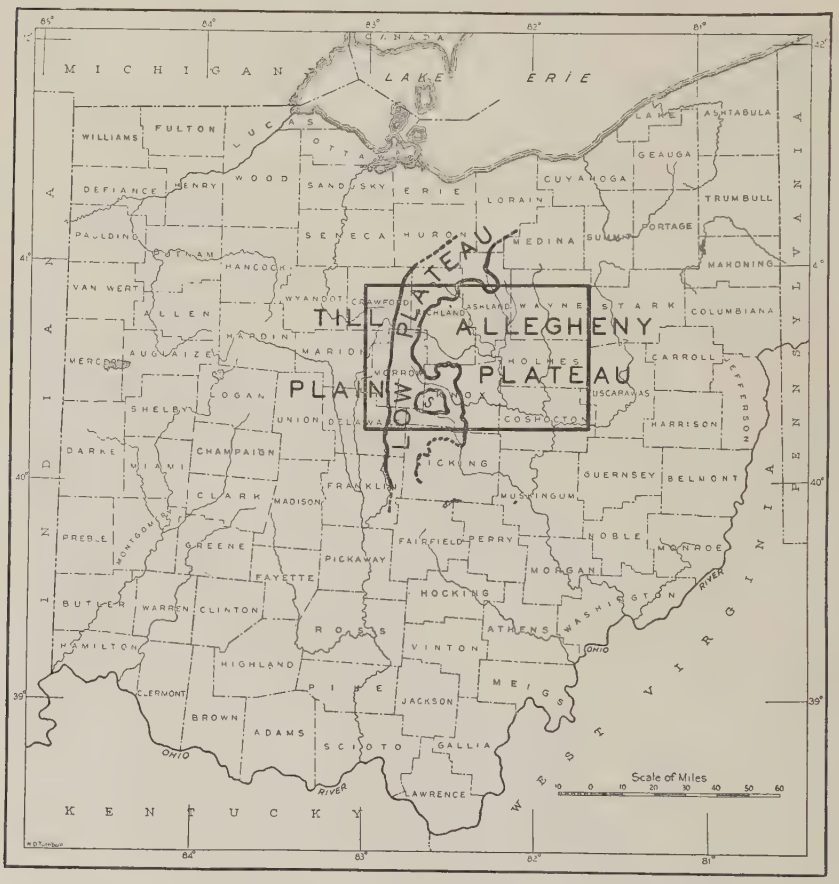

FIG. 1. Index map showing position in Ohio of area discussed, and physiographic provinces present. S.—Sparta Outlier.

is also the higher and more rugged, falls in the Allegheny Plateau section of the Appalachian Plateau province. However, study by the present writer indicates that an "inter-

[2]Fenneman, N. M. Physiographic Divisions of the United States. *Annals Assoc. Am. Geographers*, Vol. 6, 1916, pp. 19–98 and Pl. 1.

mediate plateau" intervenes between the Till Plain and the Allegheny Plateau. This lower plateau will be referred to here as the "Low Plateau." The location of the three physiographic divisions within the area and the position of the area in the state are shown on Fig. 1.

The Allegheny Plateau.—The eastern two-thirds of the area lies in the Allegheny Plateau and is the portion with which this study on drainage history is most concerned. This is in the western part of the Allegheny Plateau section of the Appalachian Plateau province which includes western Pennsylvania, the eastern half of Ohio, West Virginia, and eastern Kentucky. In the area under discussion the Allegheny Plateau is dissected to a stage of early to middle maturity, with an average relief of about 200 feet, but locally of as much as 400 feet. It varies in elevation from 1,200 to 1,500 feet, the greater elevation being due to resistant Logan sandstone of Mississippian age and to sandstones of Pennsylvanian age, which here formed a pre-Pleistocene major divide region. The concordant ridge tops of the plateau are remnants of a peneplain developed in Early Tertiary time. In eastern Ohio the peneplain has been correlated by Stout and Lamborn[3] and in this region by Ver Steeg[4] with the Harrisburg peneplain of Pennsylvania, and by Cole[5] with the Allegheny[6] peneplain of West Virginia. The northern and western parts of the Allegheny Plateau in this area have suffered glaciation, but the southeastern part is unglaciated. An outlier of the Allegheny Plateau is present in southeastern Morrow and southwestern Knox counties (see Fig. 1). The name "Sparta Outlier" is here suggested for this feature, from the village of Sparta, which is on the western end of the outlier.

The Low Plateau.—The Low Plateau is the name applied to an area having an elevation of 1,100 to 1,200 feet, lying between the Allegheny Plateau on the east and the Till Plain on the west. It is entirely covered by Wisconsin drift. In elevation, in relief, and in prominence of glacial features, this region is intermediate between its bordering regions.

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[3]Stout, Wilber, and Lamborn, R. E. Geology of Columbiana County. *Geol. Surv. Ohio Bull. 28*, 1924, pp. 38–40.

[4]Ver Steeg, Karl. Some Features of Appalachian Peneplanes. *Pan. Am. Geol.*, Vol. 54, 1930, pp. 22–24.

[5]Cole, W. S. Personal Communication; and, Identification of Erosion Surfaces in Eastern and Southern Ohio. *Jour. Geol.*, Vol. 42, 1934, pp. 285-294.

[6]Fridley, H. M., and Nölting, J. P., Jr. Peneplains of the Appalachian Plateau. *Jour. Geol.*, Vol. 39, 1931, pp. 749–755.

This physiographic division forms a gently curving belt from 5 to 16 miles in width which lies in Richland, Crawford, Morrow, Knox, and Delaware counties.

Its eastern boundary is marked by the generally abrupt rise of the Allegheny Plateau. Its western boundary is along a scarp that follows the outcrop of the resistant Berea sandstone, which rises from 50 to 100 feet above the Till Plain. The scarp is still further accentuated at places by end-moraines which lie along its top. The Low Plateau extends from this area southward across eastern Delaware and western Licking counties, and although it was not recognized by Fenneman[7] as a physiographic entity, it appears to continue to southern Ohio where it becomes a part of the Lexington plain section of the Interior Low Plateau province. The Low Plateau is part of an erosion surface cut in Late Tertiary time on the weak Cuyahoga shale and shaly sandstones of Mississippian age and is correlated with the Lexington (Worthington) peneplain. The relief of the Low Plateau varies from only a few feet to as much as 100 feet, but averages less than 50 feet. It is covered by a thick blanket of drift so that its topography is glacially controlled.

The Till Plain.—The Till Plain, which covers large parts of western Ohio, Indiana, and Illinois, extends into the western part of the area under discussion, where it forms a north-south belt varying from 8 to 15 miles in width. Its eastern boundary is the edge of the Low Plateau. The Till Plain is featureless except for the low broad swells of end-moraines and for a few large stream valleys cut 10 to 50 feet below the general level. It is a bedrock plain cut on the weak Ohio shale and the soluble Devonian limestone, and covered by a blanket of drift of rather even thickness.

PRE-PLEISTOCENE DRAINAGE

The mapping of the course of the pre-Pleistocene streams in this region is largely hypothetical. The fact that a valley is now mature, or is too wide or too deep for the stream it carries, or is abandoned entirely, does not necessarily indicate that it is preglacial in age. It may have been formed during an interglacial stage and be only earlier than the glacial advance that caused the diversion. The basic postulate in reconstructing

[7]Fenneman, N. M., op. cit.

the pre-Pleistocene drainage is that the streams had become adjusted during the long erosion interval of Mesozoic and Tertiary times and that at the end of the Pliocene the direction of the flow of the streams was the same as that of the slope of the land or, in other words, that the streams were flowing from high land to low land. Therefore, to reconstruct the ancient stream systems, it is necessary to determine the location of the major and branch divides. It may be inferred that streams drained the basins bounded by these divides. If these drainage basins slope from the plateau to the Till Plain, it may be assumed that such systems developed over a long period of time, and that they are the systems which were present at the beginning of the Pleistocene, before the first ice sheet to reach this area disrupted these ancient, adjusted, drainage lines.

The major pre-Pleistocene divide, as shown in Fig. 2, extends eastward from central Morrow County, across southern Richland County, and along the north line of Knox County to Holmes County, and thence in a general east-southeast direction to northern Mechanic Township of Holmes County, where it turns southeast and enters Tuscarawas County. This tracing in the eastern part of the region agrees with that suggested by Coffey.[8] From the major east-west divide other divides extended north and south, thus delimiting the headwaters of drainage basins. One branch divide ran north to southeastern Wayne County. Another had a north-south course in Ashland County east of the present Black Fork, but its connection with the major divide to the south is now obscure because of severe dissection by later streams. A third ran from the high land, in south central Richland County west of Mansfield, southeastward to the major divide, but its connection with the main divide has also been obscured by glacially diverted streams.

A very important divide, still well preserved, extended south from the major divide, across southwestern Holmes County and western Coshocton County, about two miles east of the Knox County line. Another extended south across Monroe and Pleasant townships in Knox County southeast of Mt. Vernon, probably reaching northern Morgan Township. From this divide a divide extended west from southwestern

[8]Coffey, G. N. Preglacial, Interglacial and Post Glacial Changes of Drainage in Northeastern Ohio with Special Reference to the Upper Muskingum Drainage Basin. *Ohio Jour. Sci.*, Vol. 30, 1930, pp. 373–384.

Monroe Township, across the long axis of the Sparta Outlier, into southeastern Morrow County. This latter divide was cut

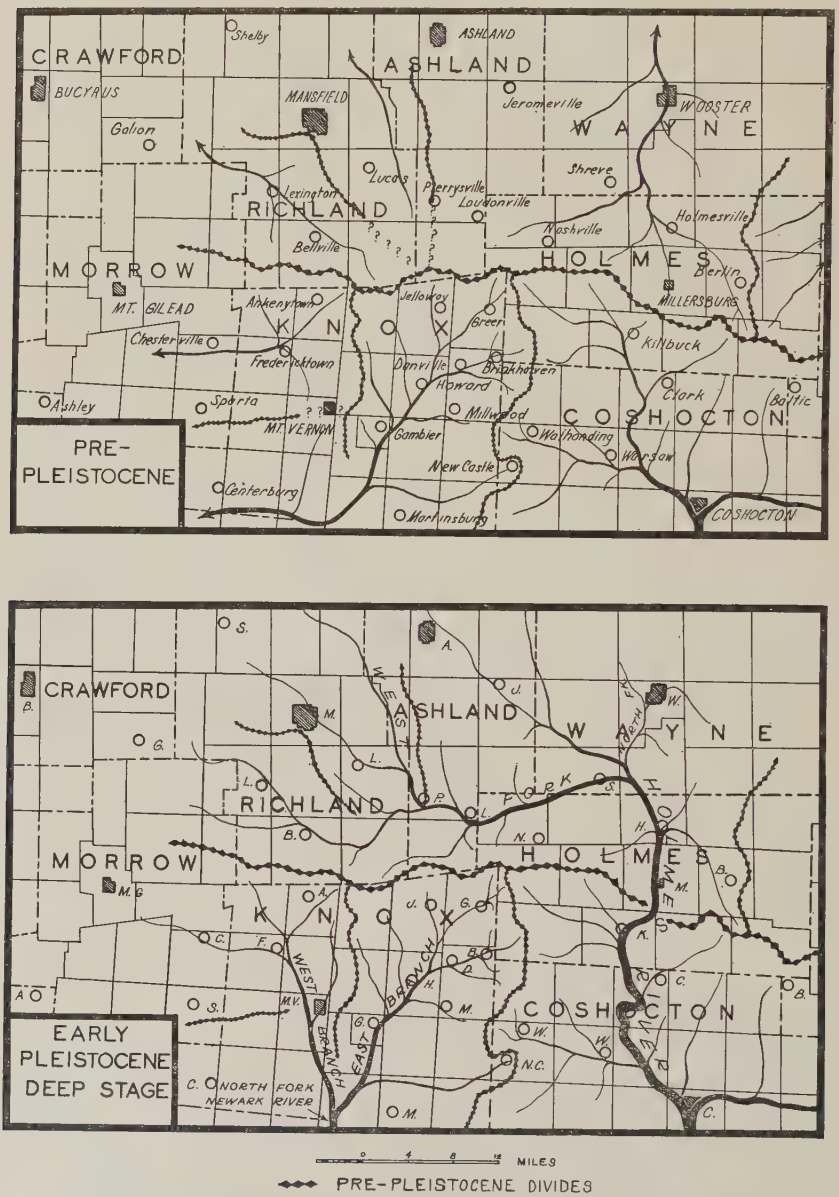

FIG 2. Maps showing Pre-Pleistocene (upper map) and Early Pleistocene (lower map) streams and divides.

through by a wide Deep Stage valley in early Pleistocene time. The Deep Stage valley is now abandoned south of Mt. Vernon.

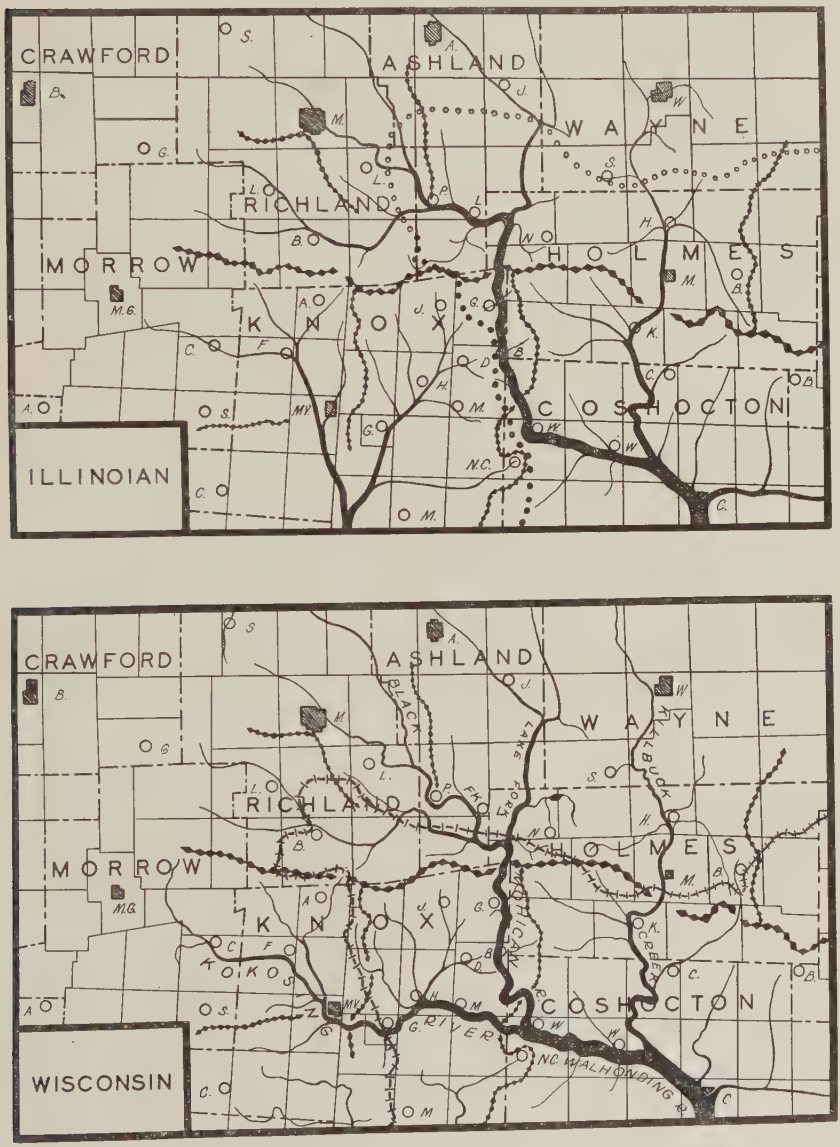

FIG. 3. Maps showing Illinoian (upper map) and Wisconsin (lower map) streams.

These divides mark out the boundaries of the headwaters of certain basins and, on this basis, hypothetical pre-Pleistocene streams are drawn as shown in Fig. 2. This region, then, had a somewhat radial system of drainage, with streams flowing outward from the highest parts of the Allegheny Plateau.[9]

This system of drainage is probably correlative with the Parker strath system in southern Ohio which was tributary to the Teays River. It is believed that the valley bottom of the Teays was above the present drainage and that the streams in its tributary valleys flowed at levels well above the present streams. As the preglacial streams in northeast central Ohio were all near main divides, their positions were probably still farther above the present water courses. On this basis, the deep valleys in northeast central Ohio are not preglacial. These shallow ancient preglacial valleys have been so cut down, or transected, and so modified by drift in the glaciated portion that they cannot commonly be identified. It must be emphasized that the streams indicated on the map, Fig. 2, are largely hypothetical, especially in the glaciated part of the area and are so mapped because each basin, marked by divides still preserved, must have been drained by a stream flowing from that basin. In the unglaciated part of the region, streams of later age may have had their courses fixed by preglacial valleys, but because of later stream work it has not been possible to identify the preglacial valleys except by inference.

EARLY PLEISTOCENE DIVERSIONS

The preglacial streams which flowed north or west from the region were partly or wholly blocked in early Pleistocene time. New systems of streams were developed which flowed from the Low Plateau southeast into the Allegheny Plateau and across divides to join streams which flowed south, eventually emptying into the newly formed Ohio River. The collected waters broke through the main divide at one place, and the col at Killbuck village is the only early Pleistocene col across the main divide in the area here discussed. Such diversions took place long before the Illinoian glacial stage. In order to explain

[9]Ver Steeg rightly concluded (Drainage Changes in the Vicinity of Wooster, Ohio. *Ohio Jour. Sci.*, Vol. 30, 1930, pp. 309–314) that no *deep* valley leads northward through Wayne county, but the present writer believes that a *high level* (Parker strath) valley must have drained northward since the divides west and south of Wayne county and in the eastern part of the county enclose a basin whose only natural outlet is northward.

them, it is necessary to postulate that an early Pleistocene ice sheet, of which so far no other evidence has been discovered, advanced to the north and west borders of the Allegheny Plateau (Fig. 1). This ice sheet may have been either the Nebraskan or the Kansan of the Mississippi valley succession.

Northward and westward flowing streams were ponded, water broke over the lowest places in divides, and stream courses were established which persisted after the ice withdrew. A long interval of time elapsed between the retreat of this early Pleistocene ice sheet and the oncoming of the Illinoian ice sheet, during which the new streams widened and deepened their valleys. Sufficient time was available for some of the large streams to partially integrate their attendant systems. Valleys were widened to a state of maturity and deepened 150 to 300 feet below the present stream levels.[10]

The pre-Illinoian valleys of this age have been called Deep Stage valleys by Mr. Wilber Stout, State Geologist of Ohio, because of the great depths of their valleys as revealed by well drilling. The name seems appropriate and definitive, and will be used in this report for early Pleistocene, pre-Illinoian valleys. The Deep Stage stream systems of northeast central Ohio are shown in Fig. 2 and will be briefly discussed.

Deep Stage Holmes River.—A Deep Stage stream which drained almost all the northern part of this area is here called the "Deep Stage Holmes River," because its ancient valley cuts across northwestern and central Holmes County. It was brought into existence by pre-Illinoian ice at the north border of the Allegheny Plateau. The dammed up waters escaped southward through the lowest place in the main divide, a col between Millersburg and Killbuck. A wide valley, which may be regarded as the West Fork of the Holmes River, now occupied in part by Black Fork, was cut by a stream which entered the Allegheny Plateau in northeastern Richland County and flowed southeast along the Richland-Ashland county line. Here it entered another valley, now occupied in part by Rocky Fork, which entered the Allegheny Plateau at Mansfield in central Richland County. The West Fork valley continued southeast into Ashland County as far as Perrysville in Green Township, where it received Deep Stage Clear Fork from the

[10] *Cf.* Ver Steeg, Karl. The Thickness of the Glacial Deposits in Ohio. *Science*, Vol. 78, 1933, p. 459; and, The Buried Topography of North-Central Ohio and its Origin. *Jour. Geol.*, Vol. 42, 1934, pp. 602–620.

west, then extended eastward past Loudonville to northern Holmes County and thence east-northeast across southern Wayne County to its junction with another large valley now occupied by Killbuck Creek, which may be referred to as the North Fork of the Holmes River. Black Fork now follows the old West Fork valley from Perrysville to Loudonville, but from Loudonville eastward past Shreve this Deep Stage valley is now abandoned. Just north of the junction of the West Fork and North Fork, the latter stream was joined by a large confluent flowing from the northwest, the West Branch of the North Fork. This branch was formed by the union of two streams flowing in the valleys occupied by the present Jerome and Muddy forks, which united just east of the Ashland-Wayne county line and flowed east, through a valley now drift blocked, past Millbrook.[11] The Deep Stage Holmes River thence flowed southward[12] across Holmes County in the valley now occupied by Killbuck Creek through a col, now almost two miles wide, in the pre-Pleistocene divide between Millersburg and the village of Killbuck. Fig. 4-A is a cross-section of this col, and shows its width and depth to be much greater than the Illinoian and Wisconsin cols (Fig. 4-B and C). South of the col the Holmes River entered a pre-Pleistocene drainage system unaffected by glaciation and the Holmes flowed south to Coshocton, where it joined tha ancient (Deep Stage) Newark River.

Deep Stage Clear Fork.—The northwestward drainage from eastern Morrow and southern Richland counties, between the major east-west divide and a branch divide, was blocked. The water found a passage eastward across the high land in Worthington Township, Richland County, and thence flowed northeast across southeastern Monroe Township, joining West Fork of Holmes River at Perrysville. In the main, present Clear Fork occupies this Deep Stage valley. For a distance of three miles near the mouth the old valley is choked with Wisconsin drift, and here the present stream has taken a new course to the south, as discussed below. At Newville, and

[11] *Cf.* Conrey, G. W. Geology of Wayne County. *Geol. Surv. Ohio, Bull. 24,* 1921, p. 18.

[12] Ver Steeg shows (op. cit.) that there is no Deep Stage valley running northward to Orrville as Todd (Some Observations on the Preglacial Drainage of Wayne and Adjacent Counties. *Ohio Acad. Sci., Spec. Pap. No. 3,* 1900) postulated. In any event, the dammed waters had to escape to the south and the Killbuck col is unquestionably Deep Stage, indicating a large southward flowing stream crossing the divide at this place.

for two miles upstream, the present Clear Fork has been forced slightly north of the Deep Stage valley by Illinoian drift filling.

The Deep Stage North Fork of Newark River.—Before the early Pleistocene ice advance, the drainage from northwestern Knox County, and that from southern Knox and southwestern Coshocton counties, was westward. Water dammed up between the east-west divide (Sparta Outlier) near Mt. Vernon and the Allegheny Plateau to the north was forced to break across the east-west divide at Mt. Vernon. The water flowed into a lake dammed up south of the east-west divide. The outlet was

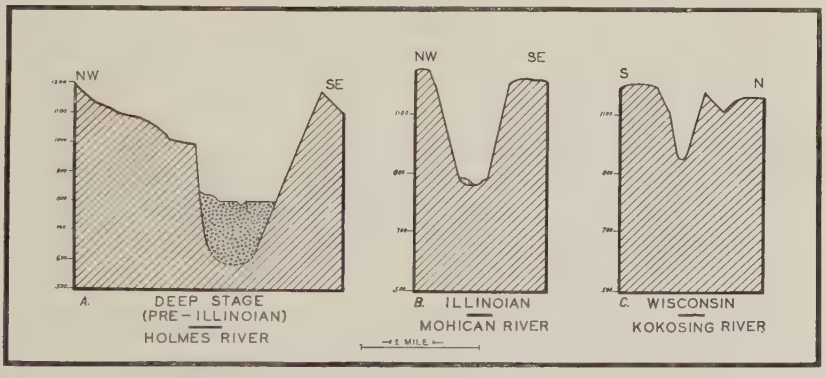

FIG. 4. Sections of cols cut across pre-Pleistocene divides by streams diverted by different ice sheets, showing relation of gorge width to age.

A. Col of Deep Stage Holmes River (now occupied by Killbuck Creek) across main divide between Millersburg and Killbuck. From NE Sec. 9, Mechanic Twp. to NW Sec 3, Killbuck Twp., Holmes County.

B. Col of Illinoian Mohican River between Brinkhaven and Greer. From NW Sec. 15, Richland Twp., Holmes County to S Sec. 10, Jefferson Twp., Knox County.

C. Col of Wisconsin portion of Kokosing River between Mt. Vernon and Gambier. From one-half mile W of Bedell School to one-half mile E of Oak Grove School, Pleasant Twp., Knox County.

established southward to Newark. This stream has been called the North Fork of the Newark River by Lamborn,[13] who has studied its Deep Stage valley in detail. He shows that the valley was formed by streams rising in northern Knox County on the southern slope of the major east-west divide and in western Coshocton County on the western slope of the subsidiary north-south divide. The present writer believes that a tributary which flowed eastward past Chesterville in Morrow

[13]Lamborn, R. E. The Newark Drainage System in Knox, Licking, and Northern Fairfield Counties. *Ohio Jour. Sci.*, Vol. 32, 1932, pp. 449–466.

County, outside the area studied by Lamborn, must have been of considerable size, and must have headed some distance west of the Allegheny Plateau border.

The tributaries to the Deep Stage East Branch of the North Fork that headed at the north-south divide in western Coshocton County can be traced eastward across the present Mohican, therefore this whole Deep Stage system is older than that stream. As the Mohican will be shown to have been forced into its present course by the Illinoian ice sheet, the Deep Stage system must be pre-Illinoian.

ILLINOIAN DIVERSIONS

The position of the ice front of the Illinoian Scioto lobe across this area has been traced in detail and will be described in another paper. Its general location is shown in Fig. 3. One very outstanding and positive drainage diversion caused by the Illinoian ice will be taken up, and then certain other diversions that are less positively attributable to this glacier will be considered.

The Mohican River.—The Illinoian ice front lay from one to five miles west of the present Mohican River in northeastern Knox County and continued just east of south across Newcastle and Perry townships of Coshocton County, from one to eight miles west of a pre-glacial north-south divide. The ice dammed the headwaters of the westward and southwestward flowing tributaries to the Deep Stage East Branch of the North Fork of the Newark River and caused the water to flow south across westward extending spurs of the north-south divide, from one headwater basin to the next, as far as southwestern Tiverton Township, Coshocton County. Here a low place in the north-south divide allowed the water to break over to the southeast and enter the valley of the Walhonding River, which then, as now, flowed east-southeast to Coshocton where it united with the Tuscarawas River.

The present Mohican valley southward across Knox and Coshocton counties (Loudonville and Brinkhaven quadrangles) varies from one-fourth mile in width, where it has cut across spurs, to one mile in width, where it crosses Deep Stage valleys. Because of its obvious association with the Illinoian ice front, this valley is regarded as Illinoian in age. Since the stream flows on bedrock where it has cut across spurs and since it cuts across headwater streams of a Deep Stage system, it is not

Deep Stage. The fact, that the Wisconsin diverted streams have narrower gorges (lower Clear Fork, Kokosing between Mt. Vernon and Gambier, and other valleys discussed below), indicates that the Mohican must be pre-Wisconsin. The greater width of one of the typical cols in the Mohican as compared with the width of a Wisconsin col, and the lesser width as compared with that of a Deep Stage col is illustrated in Fig. 4.

The age of the present Kokosing valley in eastern Knox County is as yet undetermined. The valley crosses the old north-south divide area between the villages of Millwood and Walhonding in a wider valley than that of the Mohican. Mr. R. E. Lamborn suggests[14] that a Deep Stage stream which originally headed at the village of Walhonding had, before Illinoian time, worked westward by headward erosion almost to Millwood. If this be the case, a stream may have flowed from the upper part of the East Branch drainage system to the Walhonding River just before, as well as after, Illinoian time. The present writer is of the opinion, however, that only a small stream passed through this col between Millwood and Walhonding until Wisconsin time.

Lake Fork.—Lake Fork now flows from the junction of Jerome and Muddy forks southward across southeastern Ashland County, crosses the Deep Stage valley of the West Fork of the Holmes River in northwestern Holmes County, and thence flows southwest across the south line of Washington Township to the Mohican River (West Salem and Loudonville quadrangles). The valleys of its tributaries, Jerome and Muddy forks, are two to three miles wide and are certainly pre-Illinoian (Deep Stage), but the valley of Lake Fork is only one-fourth to one-half mile wide, except where it crosses the ancient Holmes valley. On this basis it is believed not to be a Deep Stage valley. Its width is, however, greater than that of the valley of Clear Fork in Ashland County, which is canyon-like and which is quite definitely Wisconsin in age. On these bases the Lake Fork valley is believed to have come into existence with the Illinoian ice stage. To block the mouth of the Deep Stage Holmes River in southern Wayne County, and to divert the Deep Stage streams of Jerome Fork and Muddy Fork valleys from their southeastern courses to the Deep Stage

[14]Lamborn, R. E. Personal communication.

Holmes, an obstruction was necessary. It is therefore postulated that a lobe of the Illinoian glacier east of the Scioto lobe extended as far south as Shreve, but not as far as did the later Wisconsin ice, since no Illinoian drift has been discovered in this region south of the Wisconsin boundary. The location of this postulated portion of the Illinoian boundary is shown in Fig. 3.

WISCONSIN DIVERSIONS

The Wisconsin glacier advanced to the limits shown on Fig. 3.[15] Its presence caused several major diversions and many minor changes. When the Wisconsin ice had finally disappeared the streams now present, shown in Fig. 3, were established. The Wisconsin diversions will be taken up from east to west across the area.

Doughty Creek.—The headwaters of Martins Creek in southern Berlin Township, Holmes County (Millersburg and Coshocton quadrangles), ponded by the Wisconsin glacier, broke through the main east-west divide in northeastern Mechanic Township, entered Doughty Creek, and flowed southwest to join Killbuck Creek in northern Coshocton County. The course of the stream through the divide is a narrow gorge two miles in length called "Troyers Hollow." Doughty Creek and Martins Creek now rise in an area of terminal moraine topography in central and northern Berlin Township; Martins Creek flowing north from the southeastern part of the township and Doughty Creek flowing south from the northern part, their courses being only from one to two miles apart for a distance of four miles.

Sigafoos Run.—Sigafoos Run, in the western part of Holmes County (Loudonville quadrangle), suffered diversion of its lower course, which in pre-Wisconsin time was north from Knox Township to the ancient West Branch of the Holmes River in central Washington Township. The Wisconsin ice advanced as far as the south line of Washington Township, blocking the northward flowing stream and forcing it to flow westward, where it cut a narrow gorge for a mile along the front of the ice to the present Mohican River.

Black Fork.—After the Illinoian diversion of the West

[15]For details of boundary in Holmes County see White, G. W., Glaciation of Northwestern Holmes County, Ohio. *Ohio Jour. Sci.*, Vol. 31, 1931, pp. 429-453; and, An Area of Glacier Stagnation in Ohio. *Jour. Geol.*, Vol. 40, 1932, pp. 238-258.

Branch of the Holmes River, Black Fork followed the Deep Stage valley eastward from Perrysville past Loudonville to northern Washington Township, Holmes County, where it joined Lake Fork and flowed southward (Perrysville and Loudonville quadrangles). A tributary, Pine Run, flowed northeast from southwestern Hanover Township, Ashland County, and entered Black Fork at Loudonville. The Wisconsin glacier front dammed this ancient Pine Run valley two miles southwest of Loudonville. The ponded water broke over a divide eastward to the Mohican River[16] and established the present drainage course during the waning of the ice. The lower end of the old Pine Run valley was freed of ice while the old Holmes valley from Loudonville to Lake Fork was still blocked by dead ice masses. The present course of Black Fork was therefore established southwestward for two miles up the old Pine Run valley and thence eastward through the new gorge to the Mohican River.

Clear Fork.—After the early Pleistocene glaciation, Deep Stage Clear Fork flowed eastward through a wide valley from Richland County to join Deep Stage West Fork at Perrysville in Ashland County (Perrysville quadrangle). The Wisconsin ice of the Killbuck[17] lobe at the time of maximum advance covered the lower course of Clear Fork to a point about one-half mile north of Newville in northeastern Worthington Township, Richland County. However, the present Clear Fork does not leave its old valley at this place, but follows the old valley eastward along the line between Worthington and Monroe townships and into Section 31, Green Township, Ashland County, to a point only one mile from the Black Fork valley. Here Clear Fork turns southward at right angles, leaving its old valley and entering a canyon-like gorge which it follows southward into northwestern Hanover Township for two miles and thence eastward for three miles to join Black Fork. Its course in the old valley along the Worthington-Monroe township line is almost two miles north of the Wisconsin boundary, but its course in the Clear Fork gorge across northern Hanover

[16]Ver Steeg, who has called attention to this diversion (Drainage Changes in the Vicinity of Loudonville, Ohio. *Ohio Jour. Sci.*, Vol. 31, 1931, pp. 368–377) suggested it might be Illinoian. However, the position of this col, immediately south of the Wisconsin glacial boundary, and its extreme narrowness point to Wisconsin age.

[17]Name proposed for the lobe of Wisconsin ice between the "main" Scioto lobe and the Grand River lobe.

Township is just south of the glacial boundary. Such a diversion of the stream along the ice front in northern Hanover Township is to be expected, but the absence of diversion in northeastern Worthington Township is not so easily explained. The following hypothesis is offered:

The Killbuck lobe advanced into northeastern Worthington Township and dammed Clear Fork. At first the ponded waters found an outlet through a spillway in the divide at the head of the valley of Smoky Run southwest of Butler in the southeast corner of Jefferson Township, Richland County[18] and escaped into the valley of East Branch of the Kokosing River near Ankenytown. This spillway was not used very long for the Scioto lobe of the glacier advanced a little to the east of Ankenytown to a position just east of the spillway, closing the outlet. By this time, the ice of the border of the Killbuck lobe had melted away from the old valley in northeastern Worthington Township or was fissured and crevassed so that the waters again followed the old course to the southwestern corner of Green Township. However, the ice edge, or more solid ice blocks, kept the water from entering the Black Fork valley, and ponded it to a sufficient height so that it could flow south over the divide into the headwaters of a tributary of Pine Run, and thence eastward along the ice front to the point where Pine Run and Black Fork meet. From here the waters continued eastward, flowing through the new outlet established by Pine Run and Black Fork.

Kokosing River.—The course of the Kokosing River was considerably altered by the Wisconsin ice sheet. The pre-Wisconsin course of the Kokosing was southward from Mt. Vernon to the south line of Knox County, where it joined the East Branch of the North Fork of the Newark River. The Wisconsin ice blocked this valley at its mouth in southern Knox County and ponded waters found egress to the eastward across a low place in the divide at Millwood in southwestern Union Township and joined the Mohican River just east of the Knox-Coshocton county line.

The gorge by which the Kokosing crosses the divide in northwestern Pleasant Township (Gambier quadrangle) is just west of the position attained by the Wisconsin ice front. A cross-section of this Wisconsin gorge is shown in Fig. 4-C.

[18]This spillway appears to be pre-Wisconsin, although the Wisconsin boundary crosses it. It may have been the course of a minor Illinoian stream.

This gorge is explained by supposing that the marginal ice, quite thin on the divide, rapidly disappeared, while ice remained to the south in southern Morgan Township, blocking any outlet to south or east. Water had to escape over the divide between Mt. Vernon and Gambier. There is evidence of a temporary channel immediately to the north of the present gorge (see topographic map and Fig. 4-C). Finally, one channel, probably because it received more water than the other, was cut down faster, and the other was abandoned. The down-cutting was rapid, and by the time the ice disappeared from the region, drainage was established through the new gorge.

Schenk Creek.—Schenk Creek, a former tributary to the Kokosing River at Mt. Vernon, was also diverted by the Wisconsin ice sheet. This stream rises in eastern Berlin Township, Knox County, and flows southward along the Wisconsin boundary to northwestern Monroe Township, four miles north of Mt. Vernon (Gambier quadrangle). The Wisconsin ice filled the valley south to Mt. Vernon, and the ponded waters escaped eastward across a divide, along a course now marked by a narrow gorge, into the valley of Little Schenk Creek in northeastern Monroe Township. The water thence flows southeastward to the Kokosing River.

SUMMARY

It has been shown that in the Allegheny Plateau of north central Ohio there are three valley systems which cross ancient divides. The cols are of different widths (Fig. 4) and of different ages.

Narrow gorges closely related to the Wisconsin glacial boundary exist where the Kokosing, Clear Fork, Black Fork, and other streams cross divides. These gorges are believed to date from the Wisconsin glacial stage.

The Mohican River crosses divides in wider gorges, related to the Illinoian glacial boundary, and is believed to have been diverted to its present channel by the Illinoian ice.

Other valleys, where they cross divides, are deep, wide, and mature, and are manifestly pre-Illinoian. Since they cross divides, however, they were cut by diverted streams. An early, pre-Illinoian, ice sheet is believed to have caused the diversion. Valleys of this age are called Deep Stage, the two important systems in the area being the Holmes River (with North and

West forks), and the North Fork (with East and West branches) of the Newark River.

The ancient divides, here mapped (Fig. 2), are believed to mark out basins drained by pre-Pleistocene streams. The actual valleys of these streams were well above present drainage, and have therefore been so cut down, modified, and concealed by glacial drift that their exact location is very uncertain. Based on a study of the pre-Pleistocene divides and drainage basins, which slope northward, westward, southwestward, and southward, the drainage of the plateau in north central Ohio before the Pleistocene was somewhat radial.[19]

[19]ACKNOWLEDGMENTS.—The writer gratefully acknowledges his indebtedness to Professor J. Ernest Carman for many valuable suggestions made during the progress of the field work and during the preparation of most of the manuscript; to Mr. Wilber Stout for many stimulating discussions on the problems of drainage changes in Ohio; to Mr. Raymond E. Lamborn and to Dr. W. Storrs Cole for suggestions on certain points; and to Mr. John H. Edgerly for drafting the figures.

Cereal, Bamboo, and Grass

"It is now more than thirty years since, at my suggestion, Ethel Sargent sowed the grains of wheat and maize which formed the starting-point of work upon the grass seedling which we did together." . . . "The mystery abides." Thus does Mrs. Arber begin and end her book, but between those two sentences such a multiplicity of material is presented that it will long remain the source-book for those seeking information on the structure of the grasses.

Since there are over 8,000 species in the group it would be impossible adequately to incorporate the vast amount of information already accumulated and in the words of the author: ". . . I have no such encyclopaedic aim, but . . . have sought, primarily, to detect the pattern and rhythm underlying that complex of plant types called the Gramineae; . . ." Yet this central theme has not deterred her from writing three chapters on the origin and dispersal of the economic grasses; nor has it interfered with a delightful interpolation of "asides," born of a long intimacy with the comparative morphology of vascular plants, without which the book would lose much of its charm and a great deal of its stimulating philosophy.

Although primarily designed for the plant anatomist and morphologist, the book will be indispensable for the agronomist and taxonomist. Neither will the plant geneticist nor the ecologist be disappointed, for they too will find a great deal of solid information pertinent to their fields.

It is the culmination of a monumental piece of personal investigation—as evinced by the 212 text figures containing over 1,200 individual drawings and with but few exceptions, done by the author herself. It is amply appended with a twenty-one page index and a bibliography of nearly 600 titles.

For the botanist who has any preconceived notions that the problems of plant morphology have been settled, the reviewer specifically recommends Chapter 5, on the "Tree Habit" in the Angiosperms; Chapter 14 on "Morphological Categories;" and the last chapter, on the "Pattern and Rhythm in the Gramineae." They may be disturbing, but they will surely prove stimulating.—W. H. CAMP.

The Gramineae, by Agnes Arber; xvii + 480 pp. Cambridge, England, The University Press; New York, The Macmillan Co., 1934.

THE RIGHT LUNG OF A HUMAN FOETUS OF 152 MILLIMETERS, C. R., LENGTH

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I. INTRODUCTION

According to the classical accounts, the lower respiratory passages, beginning at the larynx and extending caudally to and including the pulmonary aveoli, develop from a branching diverticulum that has its origin from the entoderm of the floor of the foregut.

The earliest indication of the formation of these respiratory passages in the human embryo is a deep groove that appears on the inner aspect of the ventral surface of the primitive pharynx and oesophagus. Externally the same area presents a longitudinal ridge. Such a stage has been described in an embryo 2.5 millimeters in length by Heiss (1). As development continues the posterior end of the groove becomes a deep globular pocket. This pocket and the posterior end of the groove become a locus of rapid growth and so appear to be cut off from the more dorsally placed foregut. This apparent detachment proceeds in a cephalic direction. The globular pocket evaginates on either side and becomes bilobed. These lateral enlargements are known as the right and left stem buds.

The stem bud is the anlage of the stem bronchus. The latter structure represents the main axis of growth in the developing bronchial system and it becomes the large bronchus, which, arising from the trachea on each side, passes into the hilum and through the pulmonary substance almost to the periphery of the lung. In its course the stem bronchus gives off a series of branches known as the lateral bronchi. These branches arise as evaginations or buds from the region of the growing blind tip of the stem bronchus. The larger and more numerous of these so-called lateral bronchi are given off ventral to the main stem of the pulmonary artery as the latter structure accompanies the stem bronchus. Aeby (2) designated this group of branches as ventral bronchi while other authors have called them lateral bronchi. Smaller and less numerous branches arise dorsally from the stem bronchus and are called

dorsal bronchi. Occasional small branches arising from the stem bronchus in intermediate positions either medial or ventral have been described.

According to Narath (3) three of these branch bronchi are present in a human embryo 7.0 millimeters long. These are the right first lateral bronchus (ventral according to his terminology), the left first lateral (ventral) bronchus and the right apical bronchus. The latter bronchus was regarded as a special type and was termed the eparterial bronchus by Aeby because it arises above the pulmonary artery in contrast to all the other bronchi which are hyparterial in origin. However, Narath held that it was the first dorsal bronchus on the right side. Hungtington (4) states that except for purposes of topography we should abandon the distinction between eparterial and hyparterial bronchi. In this description of the right lung the right apical bronchus will be referred to as D1.

Other bronchi arise successively from the growing stem bronchus until there are four or five lateral bronchi (L1, L2, L3, L4, etc.) and two to four dorsal bronchi, (D1, D2, etc.). All of these are generally classed as secondary bronchi. A new generation, tertiary bronchi or bronchi of the third generation, bud outward from the secondary bronchi. From the tertiary bronchi another generation, the quaternary bronchi develop and in turn a fifth generation of tubules grow out from the quaternary group. Arey (5) quotes Broman as stating that there are in all eighteen generations of pulmonary branchings at birth.

In addition to the evaginations that appear near the tips of the growing buds, new bronchi of the later generations may arise from the blind tips by a splitting of the tip into two or three tubules of the next generation. Since the tubules of the respiratory passages arise by combinations of these methods of formation of new divisions a branching system evolves which becomes more and more like a tree.

While the general plan of development of this tracheobronchial tree is fairly constant, variations usually minor in character may occur. However, Davis (6) states that to his knowledge no other organ has so varied an arrangement of one of its fundamental structures (bronchi).

The budding bronchi grow out into a mass of mesenchyme. This mesenchymal tissue does not contribute to the formation of the lower respiratory passages.

In the last few years the classic concept of the embryology of the lung, so briefly reviewed here, has been questioned by a number of authors—Rose (7), Policard (8), Chiodi (9), Dogliotti (10), Faure-Fremiet (11), Stewart (12). The majority of the conflicting opinions center on the development of the terminal portions of the tracheo-bronchial tree and particularly on the origin and nature of the lining of the atria, air-sacs and alveoli of the adult lung.

Grosser (13) states that a number of important questions concerning the embryology of the human lung have not been settled, partly because the necessary material has not been available. It would seem that a detailed report of the anatomy of the lung of a human foetus just prior to the period of viability might be valuable as a basis for further studies.

In anticipation of a study of the tracheo-bronchial tree in the latter months of the human foetal period the author has examined the tissues of a human foetus which was aborted at about the nineteenth week of prenatal life. These tissues were found to be in an excellent state of fixation.

II. MATERIAL AND METHODS

Material.—Case History: The mother knew that she had been pregnant at least three and one-half months. She was admitted to the hospital with a complaint of vaginal bleeding which had begun following a fall that had occurred three weeks before. However, there were no signs of active hemorrhage on admission. The urinalysis and blood Wassermann test were both negative. On examination the abdomen was found to be somewhat larger than that usually seen in a pregnancy of three and one-half months duration. The foetal heart rate—153 beats per minute was distinctly heard in the left lower quadrant of the abdomen. Seven hours after the admission of the mother to the hospital the foetus was spontaneously expelled. On examination of the foetus the heart could be heard, per stethoscope, but there were no signs of any respiratory movements. A short time later there were no signs of life in the foetus and it was pronounced dead.

The foetus was of the male sex. The skin was moderately firm and no abnormalities were noted. The crown rump measurement or sitting height of the foetus was 152 millimeters. According to the formulae and charts given in standard textbooks of embryology, this measurement would place the foetus

in the nineteenth week of prenatal life. The foetus was placed in 10% formalin for forty-eight hours. At this time the anterior thoracic wall was partly removed and the pleural sacs opened. Then the foetus was placed in a fresh formalin solution. Later the lungs were observed and sketched in situ. In order to avoid many technical difficulties it was decided to make a study of only one lung. The right lung was chosen as the material to be investigated because the more complex problems of morphogenesis have centered on that lung.

Methods.—The trachea, primary bronchi, right lung and vessels, thoracic aorta, thoracic duct and thoracic portion of the oesophagus were removed en masse. The tissues were washed, dehydrated and embedded in paraffin. Serial sections of the entire mass, 20 micra in thickness, were prepared and stained with hematoxylin and eosin.

Several wax reconstructions were made by projecting the stained sections upon 2.0 millimeter beeswax plates by use of an Edinger Drawing and Projection Apparatus.

A model of the entire lung magnified to five diameters was constructed to show the distribution of the bronchi. (Plate I). A model of the stem bronchus and the origin of its branches, magnified one hundred diameters was prepared. After the stem bronchus of the lung had been modeled to its termination, one of its end branches was followed along the principal axis to its subpleural termination on the diaphragmatic surface of the lung. As the termination of this branch was approached a three-way branching was encountered. From this point outward all the divisions and subdivisions of this branching were modeled. This included an ovoid mass of pulmonary tissue that was separated from the remaining pulmonary tissue as a lobule by thin strands of connective tissue containing branches of the pulmonary vein. Other models of portions of the tracheo-bronchial tree were constructed in attempting to enumerate the number of generations of bronchi that are present in different areas of the lung.

The volume proportion of the epithelial tubules to the stroma was determined by projecting representative fields upon sheets of heavy white paper. The tubules were outlined on the paper and the sheet was weighed. Then the tubule outlines were cut out and the remaining paper weighed.

III. MORPHOLOGY

A. THE LUNG AS A WHOLE

The lung was of a uniform yellowish-white color. The chief differences noted in the appearance of this lung and that of an adult right lung were that the foetal lung was shorter from apex to base and that the cardiac impression was relatively large. The superior and middle lobes were continuous for a distance of five millimeters lateral to the anterior border, the transverse interlobar fissure being incomplete in this area and absent on the mediastinal aspect. The fine lobulations of the pulmonary tissue were plainly visible beneath the glistening transparent visceral pleura.

After fixation the lung measured 19 millimeters in vertical height (from apex to center of base). The base measured 26 millimeters in its longest antero-posterior diameter and 16 millimeters in its longest transverse diameter.

B. THE TRACHEO-BRONCHIAL TREE

1. *Trachea and Stem Bronchi.*

(a) The trachea has a position similar to that which it occupies in the adult. It is slightly compressed from anterior to posterior and the posterior surface is flattened. The lumen has a diameter of about 1.7 millimeters. The trachea terminates inferiorly by dividing into right and left stem bronchi (primary bronchi).

(b) The left stem bronchus makes a less obtuse angle with the trachea than does the right stem bronchus. The lumen of the left stem bronchus has a diameter of 1.0 millimeter.

(c) The right stem bronchus passes inferiorly and laterally after its origin at the bifurcation of the trachea. Its borders are rounded with the exception of the posterior which is flattened. Just below its origin the greatest diameter of the lumen is 1.2 millimeters. This stem bronchus gives rise to three dorsal, three lateral, one ventral and two terminal branches. The bronchial pattern formed by the right stem bronchus is as follows: D1, L1, D2, V1, L2, D3, L3, D4 and L4, respectively, from the oral end outward.

As the stem bronchus approaches the medial surface of the superior lobe a large branch is given off laterally. This is the first dorsal bronchus, D1. It arises 4.0 millimeters from the bifurcation of the trachea. The pulmonary artery lies infero-medial to the origin of D1. At a lower level the artery gives off a branch which passes anterior to the stem bronchus, then laterally and superiorly to be distributed with D1. At this second level the main stem of the pulmonary artery lies antero-medial to the stem bronchus.

The stem bronchus now passes inferiorly and laterally with the pulmonary artery being found successively antero-medial, anterior and antero-lateral. Both structures now lie well within the hilum of the lung. A large branch, L1, arises from the antero-medial aspect of the stem bronchus about 6.9 millimeters from the angle of bifurcation of the trachea. At approximately the same level a small bronchus, D2,

arises from the posterior aspect of the stem bronchus and passes postero-laterally into the hilum portion of the inferior lobe.

The stem bronchus now becomes definitely incorporated in the inferior lobe. The next branch arising from the stem bronchus is a large ventral one, V1, which has its origin 8.7 millimeters from the bifurcation of the trachea. The stem bronchus then passes postero-laterally as well as inferiorly. The next bronchus arising from the stem bronchus is a lateral branch, L2. According to Narath the dorsal bronchi are usually fewer in number than the ventral bronchi. L2 arises 10.4 millimeters from the tracheal bifurcation.

A small dorsal bronchus, D3, arises posteriorly from the stem bronchus, 11.9 millimeters from the tracheal bifurcation. At the same level a ventral branch, L3, is given off antero-laterally. After passing posteriorly and inferiorly the stem bronchus terminates by dividing into two bronchi, a smaller postero-medial, D4; and a larger antero-lateral bronchus, L4. This point of termination is 13.0 millimeters from the trachea.

When the right stem bronchus is viewed from above, as from the position of the trachea, a definite spiral curvature is noted in its course. This curvature is clockwise in direction when viewed from the above mentioned position. A similar curvature is present in the course of some of the branches of the stem bronchus, being especially well marked in the fourth lateral bronchus. In the latter case the branches of L4 arise in alternating planes which are at right angles to each other; that is one branch is given off in a transverse plane and the next in an antero-posterior plane.

2. *Bronchi Arising Directly from the Stem Bronchus.*

(a) D1. (Apical Bronchus, Eparterial Bronchus.)—This bronchus arises from the lateral side of the stem bronchus and passes laterally and slightly anteriorly into the hilum portion of the superior lobe. About 0.6 millimeters from its origin, D1 gives off a large posterior branch, D1p, which gives origin to all the bronchi which supply an area bounded by the posterior one-fourth of the costal surface and all of the oblique fissural surface of the superior lobe. (Plate I.) The terminal tubules from this posterior branch reach almost to the apex of the superior lobe. D1 then passes inferiorly and antero-laterally giving off a series of branches. These branches supply the remainder of the superior lobe, namely, an area bounded by the mediastinal, transverse fissural and anterior three-fourths of the costal surface of the superior lobe.

(b) L1. (Bronchus to Middle Lobe—First Lateral Bronchus.)—L1 gives origin to all the tubules found in the middle lobe of the right lung. This bronchus arises from the antero-medial aspect of the stem bronchus as the latter lies in the hilum of the lung. The main stem of the pulmonary artery is lateral to L1 at the point of origin of the latter from the stem bronchus. L1 passes inferiorly, anteriorly and somewhat laterally entering the hilum portion of the middle lobe. At this point L1 gives off a large posterior branch, L1p, then passes downwards and forwards and gives origin to all the bronchi found in the area bounded

by the mediastinal surface, antero-medial four-fifths of the diaphragmatic surface, and anterior two-fifths of the costal surface of the middle lobe. The posterior branch passes downwards, laterally and slightly forwards and supplies all the bronchi found in the remainder of the middle lobe, namely, the area bounded by the postero-lateral one-fifth of the diaphragmatic surface, the lateral three-fifths of the costal surface and by the surface facing into the oblique interlobar fissure.

(c) D2. (Second Dorsal Bronchus.)—This bronchus arises in the hilum of the lung from the posterior aspect of the stem bronchus. The lumen of D2 measures 0.6 millimeter in diameter. The second dorsal bronchus passes postero-laterally into the hilum portion of the inferior lobe about 5.3 millimeters below the most cranial or apical portion of that lobe. D2 arises posterior to the main stem of the pulmonary artery and the branch of that artery which is distributed with D2 lies along the lateral side of the latter structure. D2 almost immediately gives off a posterior branch which gives origin to the bronchi found in the area bounded by posterior half of the costal surface of the inferior lobe from the apex extending downward for about 7.0 millimeters. After giving origin to this posterior branch, D2 continues downwards and laterally giving origin to the bronchi of the inferior lobe in the area antero-medial to that supplied by the posterior branch. The lower limit of the bronchial distribution of D2 may be marked by a line which is almost transversely placed but which is slightly higher along the vertebral margin of the lung and curves across the costal surface to within a millimeter of the oblique interlobar fissure, then turning somewhat upwards to meet the fissure.

A marked similarity is noted in the location of site of origin from the stem bronchus, the branchings and the areas supplied by bronchi D1 and D2. The mass of lung supplied by D2 is in fact a miniature of the superior lobe, which is supplied solely by D1. Such a similarity, although less marked, will be pointed out between bronchi L1 and L2.

(d) V1. (First Ventral Bronchus—Infra-cardial Bronchus.)—This bronchus arises from the antero-medial aspect of the stem bronchus. At the site of origin V1 is medial to the main stem of the pulmonary artery. The lumen of V1 has a diameter of 0.5 millimeter. V1 passes directly downward into the hilum portion of the inferior lobe and gives off a lateral branch, then continues downward into the antero-medial portion of the inferior lobe. The first ventral bronchus supplies all the bronchi found in an area bounded by the mediastinal surface of the inferior lobe below the hilum and by the antero-medial two-fifths of the diaphragmatic surface of the inferior lobe.

(e) L2. (Second Lateral Bronchus.)—This bronchus arises from the lateral portion of the anterior aspect of the stem bronchus. At its site of origin L2 lies medial to the main stem of the pulmonary artery. The lumen measures slightly over 0.4 millimeters in diameter. L2 passes downwards, forwards and laterally and gives off a large lateral branch. Then it continues downwards and forwards. The second lateral bronchus supplies a wedge-shaped segment of the inferior lobe below the level of the hilum. The surfaces of this segment are a vertical strip of the costal surface along the oblique inter-lobar fissure, the

lateral half of the surface facing into the fissure and the antero-lateral one-fifth of the diaphragmatic surface.

In lower animals the lung is clearly made up of a series of superimposed tiers, each tier being supplied by a dorsal bronchus and its fellow lateral bronchus with the accessory bronchi that may be present at that level. In the human lung this system of tiers while not so distinct may still be traced by referring to the various views of the model prepared to show the distribution of bronchi (Plate 1). Each successive tier lies medially, inferiorly and posteriorly to the preceding tier. The first tier has far outgrown the others, forming the superior and middle lobes. The portion of the lung constituting the second tier supplied by D2, V1 and L2 is somewhat of a miniature of the superior and middle lobes supplied by D1 and L1, respectively.

(f) D3. (Third Dorsal Bronchus.)—This bronchus arises from the posterior aspect of the stem bronchus as the latter lies deep in the interior of the inferior lobe. D3 passes directly backwards into the inferior lobe posterior to the main stem of the pulmonary artery. The lumen of D3 has a diameter of 0.2 millimeter. The third dorsal bronchus supplies a wedge-shaped segment of the inferior lobe. This segment is flattened from above downwards and has its base on the middle portion of the costal surface of the inferior lobe.

(g) L3. (Third Lateral Bronchus.)—This bronchus arises from the antero-lateral aspect of the stem bronchus medial to the main stem of the pulmonary artery. The lumen of L3 measures 0.4 millimeter in diameter. L3 passes downwards and laterally, gives off a postero-lateral branch and then continues downward. The third lateral bronchus is distributed to a wedge-shaped segment of the lower half of the inferior lobe. This segment borders on the postero-lateral portion of the costal surface and on the postero-lateral one-sixth of the diaphragmatic surface of the inferior lobe.

(h) D4. (Dorso-Medial Terminal Branch of Stem Bronchus.)—The lumen of this bronchus measures 0.4 millimeter in diameter. The bronchus passes postero-laterally and inferiorly and is distributed to a tetrahedronal segment of the lower half of the inferior lobe. The base of this segment is on the postero-medial portion of the costal surface.

(i) L4. (Antero-Lateral Terminal Branch of Stem Bronchus.)—The lumen measures 0.6 millimeter in diameter. L4 passes inferiorly and is distributed to a wedge-shaped segment of the lower half of the inferior lobe. This segment borders on the most convex portion of the costal surface and on the posterior one-fifth (approximately) of the diaphragmatic surface.

3. *Branches Arising from the Direct Branches of the Stem Bronchus.*

It seems questionable whether all the direct branches of the stem bronchus should be classed as secondary bronchi. The report of Narath on the morphology of the bronchial system in a human embryo of 7.0 millimeters in length seems to justify the application of the term secondary bronchus or bronchus of the second generation to D1 and L1 since they apparently arise proximal to the growing tip of

the stem bronchus. Whether the remaining branches of the stem bronchus should be classed as secondary bronchi remains a problem until a larger series of early human embryos have been studied. This same lack of a more complete series prohibits the classification of the branches of D1 and L1 as secondary stem bronchi with tertiary branches although such a pattern seems to be common to each of them. However, in each of these bronchi the first branch is a posterior one and is almost as large as the parent secondary bronchus which continues on from the site of origin of the branch. From the bronchi arising from the stem bronchus and from the branches of these bronchi many generations of tubules arise. As yet there seems to be no exact way of determining what generations of these will develop into the bronchi and bronchioles of the adult lung. Following the example of Kolliker (14) we may denote all the branches as tubules. The determination of the exact number of generations of tubules present in the simple tracheobronchial tree of a young embryo is a difficult problem, and the difficulties are greatly multiplied in the study of the tree in a foetus in the nineteenth week of prenatal life. It is fairly well agreed that new tubules may arise by any one or by combinations of three methods, namely, lateral budding (monopodial), dichotomous branching and trichotomous branching. No definite regularity in the appearance of these methods of tubule formation has been described. Furthermore, in examining an embryological specimen it should always be remembered that the growth processes may have obscured the forms of an earlier stage. A dichotomous branching may later appear to be a larger bronchus giving off a smaller side branch due to more rapid growth in one of the pairs of bronchi previously formed by the dichotomous division.

It is apparent that a definite rule is necessary before determinations of value can be obtained. Accordingly the following rules have been observed in making the determinations of the number of generations of tubules present in the different lung areas listed. First, some type of reconstruction or models should be prepared from a complete set of serial sections. A model is necessary so that no branches will be overlooked, and is especially desirable in studying the finer ramifications where new tubules arise from many aspects of the parent stems.

Second, when tracing along a tubule and its first branch is encountered, that branch should be given a number denoting the succeeding generation. Then this branch is traced along its course and the tubule previously being traced is disregarded. This branch is followed until its first branch is found and then this latter branch is given a number denoting another generation and it is followed, etc. If a division with branches of equal size is found, the one that is distributed to the more orally located area is assumed to be the branch.

This method seems reasonable and necessary because it is an assumption to treat a small bronchus as a branch of a large bronchus in every case, whereas the two may have at an earlier period been fellow members of a dichotomous branching, after which one (the assumed main bronchus), grew more rapidly. Using these rules the following results were obtained:

Superior Lobe.—Considering D1 as a secondary bronchus (generation 2) there are sixteen generations of tubules present.

Middle Lobe.—Considering L1 as of generation 2 there are seventeen generations of tubules present. In the particular region examined the seventeenth generation was just in the process of formation, being represented as paired evaginations of the blind end of the preceding tubule, (generation 16).

Inferior Lobe.—The number of generations of tubules arising from the remaining dorsal bronchi was determined by the same method. If these bronchi (D2, D3 and D4) are considered as bronchi of the second generation the results are: D2, 15 generations; D3, 14 generations; D4, 13 generations. It is interesting to note the progressive decrease in the number of generations from the successive dorsal bronchi. It suggests a correlation with the tier structure of the lung that is so much more apparent in lower animals. However, D2, the dorsal representative of the second tier, may be considered a bronchus of the third generation and then the number of generations in this area will be 16, the same number as was found in the area of D1.

The first seven or eight generations of bronchi lie within definite connective tissue septa while the remaining generations lie within and largely make up the areas inclosed by less distinct septa.

C. LUMINA

In the first seven or eight generations, whose walls are rigid, the margins of the lumina are markedly serrated due to the longitudinal foldings of the inner coats of the bronchi. In the remaining generations the lumen is small but usually distinct. The lumen in these latter tubules is greatest at the site of origin of branches and at the blind ends of the tubules. These terminal expansions do not appear to be as large relatively as the terminal buds observed at earlier periods in the development of the tracheo-bronchial tree. Merkel (15) quotes Kolliker as stating that air-cells begin to be formed in the sixth month of foetal life and that in the beginning of the fifth month the end buds measure 0.09 to 0.13 millimeter in diameter.

In this foetus the following diameters were found for the lumina of two sets of generations of bronchi: (diameters in millimeters).

Generation	D1	L1	Generation	D1	L1
2	.70	.60	10	.08	.08
3	.41	.46	11	.07	.06
4	.29	.35	12	.05	.06
5	.26	.28	13	.05	.05
6	.18	.14	14	.03	.03
7	.11	.12	15	.03	.03
8	.09	.09	16	.04	.03
9	.09	.09	17	....	.03

These measurements are of only one successive line of tubules in the respective areas. The size of the tubules of one generation is variable among the larger tubules but the terminal generations are of a uniform size throughout the lung, the lumen averaging about 0.03 millimeter and the entire tubule 0.05 millimeter in diameter.

D. BLOOD VESSELS

1. *The Pulmonary Artery.*

The right branch of the pulmonary artery passes directly laterally from its origin and then turns downward in front of the stem bronchus at a point just inferior to the origin of bronchus D1. The lumen of the artery has a diameter of 1.4 millimeters. Corresponding to the bronchi the main arterial trunk or stem artery gives origin to a branch for each bronchus that arises from the stem bronchus. The arterial branches arise at a slightly higher level than the bronchi which they accompany but are given off in a plane exactly parallel to the plane in which the bronchus arises. The arterial branches pass outward on the lateral aspect of their corresponding bronchi.

2. *The Pulmonary Veins.*

The small venous channels lie between the pulmonary lobules. The upper pulmonary vein drains the superior and middle lobes, the vein from the superior lobe passing anterior to both the stem artery and the stem bronchus while the veins from the middle lobe converge to form a trunk that lies medial to the first lateral bronchus. The lower pulmonary vein, draining the inferior lobe, lies posterior to the stem artery and the stem bronchus.

3. *Bronchial Vessels.*

The bronchial arteries are very small and together with the bronchial veins are found lying on the posterior aspect of the stem bronchus.

E. LYMPH GLANDS

There are two tracheo-bronchial lymph glands present, the largest measuring 1.1 by 1.8 millimeters in cross-section. There were probably other members of this particular group of glands that were not removed from the thorax. There are four intertracheo-bronchial glands (glands of the bifurcation) and nine broncho-pulmonary glands present. No members of the pulmonary group of lymph glands were observed.

F. NERVES

The right vagus nerve lies longitudinally along the right postero-lateral aspect of the trachea. From this nerve a large branch passes along the posterior surface of the stem bronchus into the hilum of the lung. Here it breaks up into smaller branches which accompany the bronchi arising from the stem bronchus. Nerves could not be traced beyond the fifth generation of tubules. A specific nerve stain was not employed. One or two other small nerves are present in the outer wall of the stem bronchus, but their exact origin was not determined.

IV. HISTOLOGY

A. THE TRACHEO-BRONCHIAL TREE

1. *Epithelium.*

The epithelium of the oral end of the tracheo-bronchial tree is of a ciliated pseudo-stratified columnar type containing the same four types

of cells as the epithelium of the adult trachea; namely, basal, intermediate, ciliated and goblet cells. A typical cuticular border is present. The goblet cells are few in number and are apparently immature, being more nearly the shape of a spear-head than that of a goblet. Over the free surface of the goblet cell the cuticular border dips in away from the lumen and cilia are absent. No goblet cells were observed that were in the process of extruding mucin. Goblet cells are not found below the origin of bronchus L2.

This ciliated pseudo-stratified type of epithelium lines the entire extent of the stem bronchus and continues out along the branches of the tracheo-bronchial tree as far as the sixth or seventh generation of tubules. In these generations the intermediate cells are not numerous and soon disappear entirely. From the sixth or seventh generation to and including the tenth generation the epithelium is ciliated pseudo-stratified consisting of two cell types, the pyramidal basal cells with irregular smaller darkly staining nuclei and scant cytoplasm and the slender ciliated cells with oval or flattened nuclei placed at right angles to the cuticular border. These ciliated cells extend down between the basal cells with tapering ends and the cytoplasm is more abundant at the cuticular pole of the cell.

The epithelium is not ciliated beyond the tenth generation of tubules. In other respects it is like that of generations 6 or 7 to 10 as far as generation 13. In the case of both D1 and L1 the origin of generation 14 is marked by an abrupt change of the epithelium to a simple cuboidal type. In vertical section the outline of these cells is practically square. The nucleus is large, round and centrally placed with fine scattered chromatin granules. The cytoplasm takes a moderate amount of stain and appears structureless. In generations 15, 16 and 17 the cytoplasm is more abundant, seems rarefied, stains lightly, and the nuclei are much more vesicular. This peculiar condition of the cells of the smaller tubules has been noted by Dogliotti and Amprino (16).

In all the regions examined throughout the entire tree the epithelium forms a continuous lining from trachea to the blind ends of the terminal generations. At no point was there any evidence of a break in the epithelial lining or of local death of tissue. No areas were observed in which parts of the lining cells were being desquamated.

2. *Basement Membrane.*

The basement membrane of the oral end of the tree is thicker than in the smaller divisions. The epithelial cells rest directly on the reticulum fibers of the stroma throughout the extent of the tubular system, and the basement membrane is intact throughout.

3. *Glands.*

The tracheal glands are very numerous and are of a compound tubulo-alveolar type. In the alveoli two types of glandular cells are found, namely, cuboidal granular cells of a serous nature and columnar mucin containing cells. In the trachea typical crescents of Giannuzzi were noted. The ducts, near the alveoli, are lined with a cuboidal epithelium, but the lining becomes pseudostratified near the orifices of the ducts. The stem bronchus contains fewer glands than the

trachea and the alveoli of the glands consist almost entirely of serous cells. As the branches of the stem bronchus are followed outward, glands are present as far as and including the seventh generation. In the smaller tubules many of the glands are still in a simple tubular stage.

4. *Cartilage.*

In the trachea several of the C-shaped rings are completely formed, while in the bronchi the cartilage is present in the form of plates. The cartilage extends out as far as and including the eighth generation of branchings.

B. STROMA OF THE LUNG

The stroma consists of fibroblasts rather loosely and irregularly arranged between the tubules. In the walls of the first eight generations of bronchi, chrondoblasts and the appearance of cartilage are noted. There is no particular condensation of the stroma about the walls of the remaining generations of tubules. The stroma lying between the terminal ramifications is quite avascular. This observation is contrary to that of Rose, but is supported by the studies of Dogliotti. A high power microscopic field of the lung tissue resembles that of a compound tubular gland in many ways, although the stroma is relatively great in amount in the lung at this stage. Studies of areas in which no large bronchi or vessels are present show that the stroma makes up about 79% of the mass of the pulmonary tissue. Free cells are very occasional in the stroma and seem to be of the cell type usually described as clasmatocytes.

C. LYMPH GLANDS

The largest of the lymph glands have a typical peripheral sinus but there are no secondary nodules or "germinal centers" present. The gland is made up of closely packed cells which appear to be large lymphocytes for the most part. However, there are considerable numbers of free polymorphonuclear cells. The lymph glands appear relatively vascular.

No peculiar histiologic characteristics at this stage were noted in the other structures described in the section on Morphology.

V. SUMMARY

1. The bronchial tree of a human foetus of 152 millimeter length (c. r.) has a continuous intact lining of epithelium.

2. According to a method of enumeration outlined, there are seventeen generations of tubules present as a maximum number. In such a location the first thirteen generations are lined by a pseudo-stratified epithelium, the remaining four generations have a cuboidal epithelium.

3. In the terminal generations of tubules (last two or three) the epithelial cells are relatively large, with round vesicular nuclei and abundant cytoplasm that appears to be rarefied.

4. The terminal tubules have a diameter of 0.05 to 0.06 millimeter.

5. The more oral the site of origin of a branch bronchus from the stem bronchus the greater the number of generations of tubules that have arisen from this branch bronchus.

6. When viewed from above, there is a marked clock-wise rotation of the stem bronchus in its course.

* * * * * * * * *

I am indebted to Professor R. A. Knouff, who suggested this problem; to Miss Thelma Baird, who prepared the serial sections, and to Miss Florence Melvin, who prepared the illustrations.

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EXPLANATION OF PLATES

Plate I

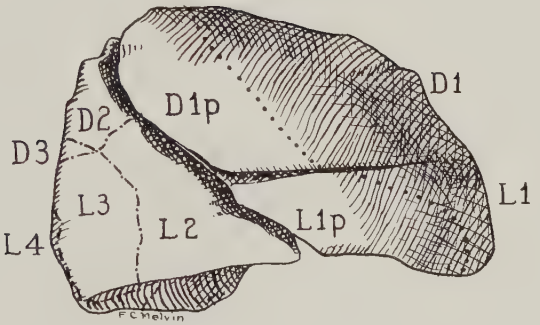
Right Lung. Surface areas of bronchial distribution. Lateral, Dorsal, Medial and Diaphragmatic views of a wax reconstruction.

Areas: D1, First Dorsal Bronchus except its first branch which is indicated by D1p. L1, First Lateral Bronchus except its first branch which is indicated by L1p. Other dorsal bronchi, D2, D3 and D4. Other lateral bronchi, L2, L3 and L4. V1, First Ventral Bronchus (Infracardial bronchus). Tr., Trachea. RSB, Right Stem Bronchus. × 2.

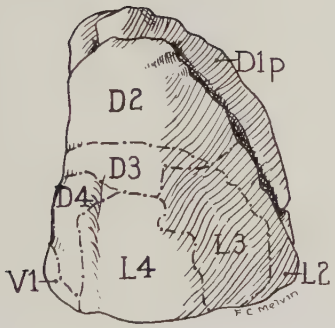
Plate II

Semidiagramatic sketches of epithelium of tracheo-bronchial tree.

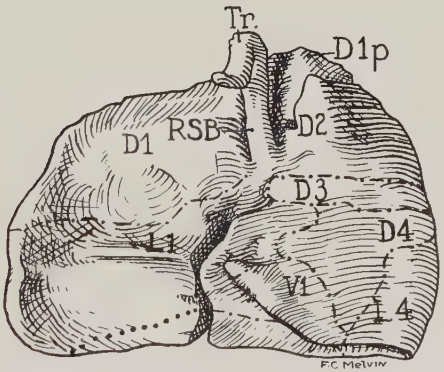
G, Goblet cell; CI, Ciliated cell; I, Intermediate cell; B, Basal cell; CO, Nonciliated columnar cell; CU, Cuboidal cell; L. CU, Light-staining cuboidal cell. × 550.



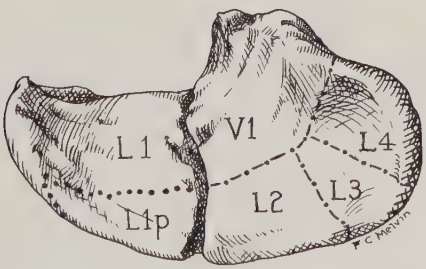
Lateral



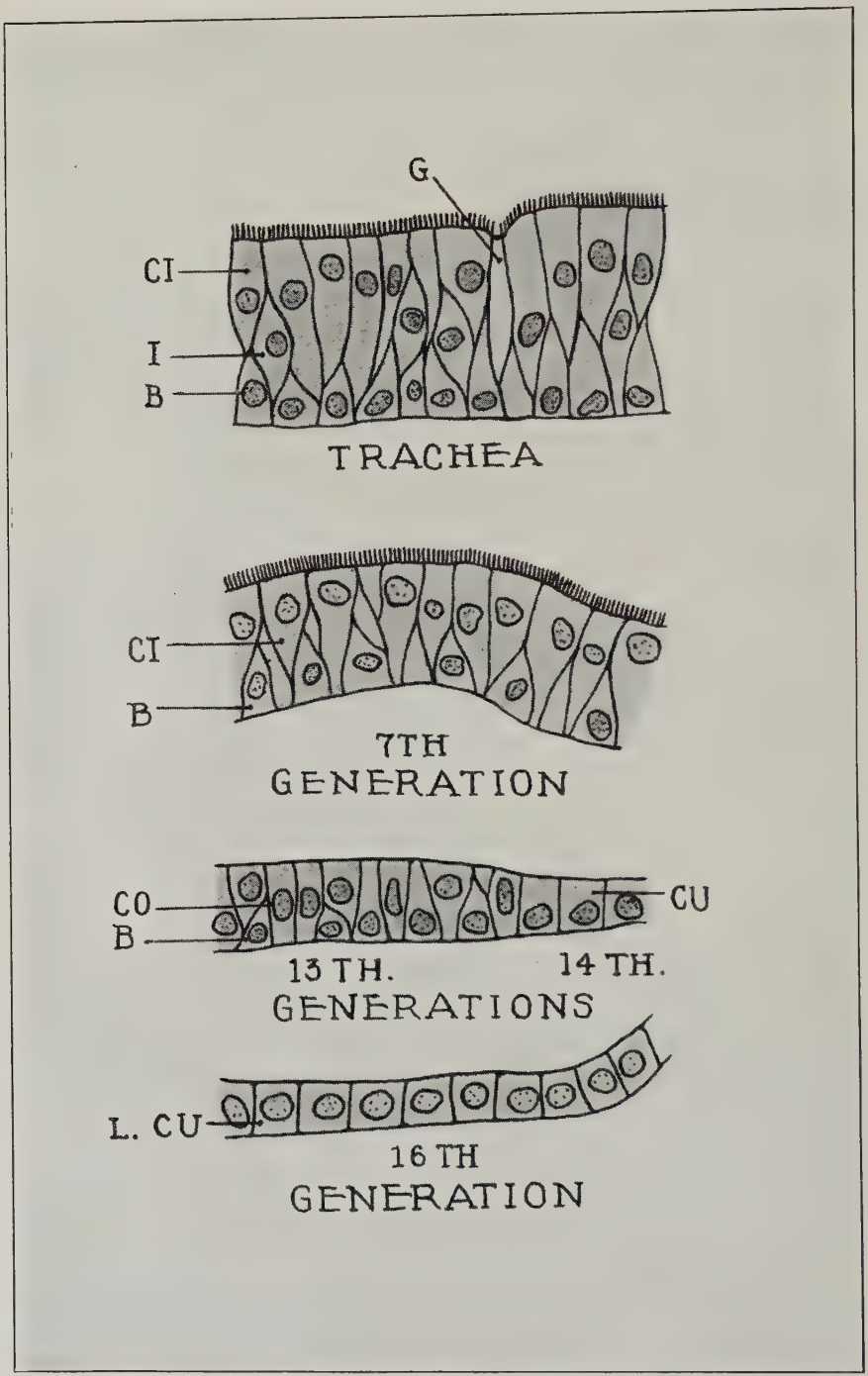
Dorsal



Medial



Diaphragmatic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THE EMBRYOLOGY OF THE WHITEFISH *COREGONUS CLUPEAFORMIS*, (MITCHILL)

Part II. Organogenesis

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FOREWORD

In the first paper of this series,[1] the early embryology of the whitefish from fertilization up through the closure of the blastopore (Stage 128, O. S. U. series) was described. The later stage marked the completion of the first third of the incubation period in terms of thermal units, although the embryo had been incubated only one-sixth the number of days usually required by this species before hatching in lake water of winter temperatures. The embryo was about 3 mm. long, and it lay without torsion and clearly outlined over the curvature of the yolk. In its anterior end, the three primary brain lobes were present and the neural keel of the head region lay deeply imbedded in the yolk. The optic primordia were prominent, lateral to the forebrain and were attached to the latter by broad optic stalks. Neither the brain nor the optic anlagen possessed cavities in this stage and hence have not yet acquired the vesicular condition. A thickened ectodermal plate lay on each side of the neural keel lengthwise. This sensory plate possessed an indistinct sensory furrow. The notochord had extended its full length forward to end beneath the midbrain. Eleven pairs of somites were present, with the most anterior one lying at the level of the hind brain. The entoderm was described as being thin and unfolded throughout its length. Kupffer's vesicle was seen here in its stage of maximum size.

From this condition as a point of departure, the present paper describes the general embryology and development of the whitefish up through Stage 400 of this series, which marks the completion of the first half of the incubation period.

Stage 144. O. S. U. Series.—(Incubation period, 24 days, 20 hours; 112.5 T. U.; fourteen pairs of somites.) The embryo lies as in the

[1]The Embryology of the Whitefish. Part I. Early Embryology. Ohio Jour. Sci., Vol. XXXIV, No. 5, 1934.

previous stage prominently elevated above the yolk surface, without torsion. It now extends about one-half the distance around the curvature of the yolk. Marked cephalization is expressed in the prominence of the three primary brain lobes and of the optic vesicles. The latter are now well developed sac-like structures whose walls are composed of a single layer of columnar cells. The cavity within is confluent with a small one within the brain stem which appears in this stage for the first time as the result of continued delamination and final separation of the cells of the neural keel in that region. This cavity is the third ventricle. Elsewhere in the brain region, the cells are not definitely separated, but their nuclei are drawn out to the sides of the keel, and their inner ends are interlocked. Their nuclei thus form two distinct rows, one on each side of the mid-line. The central portion of the sensory plate has become invaginated at the level of the hind brain to form a thick-walled auditory pit, with a small central canal. A thickened ectodermal plate lays anterior and continuous with it to form the pre-auditory sensory plate. In the posterior end of the notochord, the cells are definitely wedge-shaped and interlocked. Their nuclei are migrating laterally toward the periphery, preparatory to vacuolation of the notochord. The entodermal sheet retains its unfolded condition forward to the branchial region at the level of the first anterior somite. Anterior to this level it becomes folded on itself dorso-laterally to form a conspicuous branchial fold on either side. However, the floor of the pharynx is incomplete in the mid-line. Just anterior to the auditory pit, this projects distally as a pouch to meet a plate of surface ectoderm on the side of the head to mark the location of the first branchial cleft. Just anterior to this, the hyomandibular pouch extends more vertically, but does not reach the surface ectoderm. From this point forward the branchial folds flatten out and the pharynx ends just beyond the end of the notochord. Lateral to the branchial folds on either side lies a sheet of splanchnic mesoderm which is folded inward to enclose minute paired pericardial cavities. The cells on the mesial border of these folds are somewhat elongated. Inward from them lie clusters of cells derived from intermediate mesoderm, which are destined to form the endocardial lining of the heart.

Stage 160. O. S. U. Series.—(Incubation period, 27 days, 12 hours; 115.1 T. U.; 21 pairs of somites; total length of embryo, 3.5 mm.)

The embryo has undergone an orderly increase in length and in the number of paired somites during the two and a half days of incubation since the previously described stage. The brain has increased in size, with thicker walls. The third ventricle is more pronounced in the surface view, and now extends as a narrow cavity above the floor of the prosencephalon throughout its length. The optic vesicles likewise are larger than in the previous stage. They have now become laterally compressed and invaginated to form a two-layered optic cup. The elongated columnar cells which line the cup to form the thickened retinal layer are now separated mesially from the thinner peripheral layer of cells by a narrow cavity, confluent with that of the optic stalk and third ventricle. Ventrally, the optic cup is indented by the choroid

fissure, which is formed as the result of the invagination of the cup, and which persists until after the hatching stage. The small area of surface ectoderm which covers the center of the optic cup is thickened at this stage to form the primordium of the lens. A slight invagination of a thickened ectodermal placode on each side of the mid-line, on the antero-ventral surface of the head marks out for the first time the location of the nasal pits. The auditory pit, described in the previous stage, has sunken further beneath the surface and now forms the auditory vesicle, whose thick walls are composed of a single row of columnar cells concentrically arranged. Its mesial surface comes to lie in close proximity to the sides of the hind brain. The branchial folds, first described in the previous stage, are more conspicuous in cross-sections than before. The hyomandibular pouch now is in contact with a thickened ectodermal plate on the outer surface of the head. The first branchial pouch immediately behind it clearly extends to the surface ectoderm, laterally beneath the anterior portion of the auditory vesicle. Cross-sections at these levels closely approximate the conditions shown in Figures 56 and 59, Plate XVI—Swaen *et* Brachet—1900. Anterior to the hyomandibular pouch the entoderm has folded on itself to complete the floor of the pharynx in the mid-line by a thin strand of cells. The pharynx ends blindly as before.

The endocardial masses from each side slightly in advance of the level of the auditory vesicle have met each other in the mid-line beneath the enclosed portion of the pharynx, forming a single, loosely connected endocardial mass. The folded layers of splanchnic mesoderm bounding the pericardia have accompanied the endocardial masses in their migration inward and now lie ventro-lateral beneath the pharynx. See Fig. 16, Pl. XVII, Swaen et Brachet, v. 16.

There are apparently 21 pairs of somites present. In the anterior somites particularly, the cells on the ventro-mesial border are assuming the mesenchymal characteristics of the sclerotome. The latter lies adjacent to the notochord.

In Stage 112, the intermediate mesoderm in the region of the anterior somites was described as a single line of cells which at that time lies between the somite and the lateral mesoderm. Now these cells have increased in number, have migrated ventrally and form a wedge-shaped mass ventro-lateral to the sclerotome and dorsal to the entoderm. These masses of intermediate mesoderm will later complete their migration from each side and occupy the space in the mid-line beneath the subnotochordal rod, there to give rise to the blood and definitive vessels in this region.

In Teleosts, the intermediate mesoderm is not segmented, and hence the primitive excretory organ does not form as a series of pronephric tubules but rather as a single pronephric chamber.

At the level of the 4th, 5th, and 6th somites, a secondary plate of intermediate mesoderm, which has not migrated as above but has retained its primitive position on the mesial face of the lateral mesoderm, gradually becomes differentiated from the latter to form the pronephric chamber. This differentiation appears first as a thickening of this plate. Its ventral mesial border becomes folded sharply to grade imperceptibly

into the splanchnic layer of the lateral mesoderm. Later, when the cavity of the splanchnocoele forms, it will penetrate between the folded cell layers of this plate to form the lumen of the pronephric chamber. From the level of the 7th somite backwards, the cells of the secondary intermediate plate become constricted off from the mesial face of the lateral mesoderm to form a solid cord of cells which appears as a rosette in cross-sections. This line of cells becomes the pronephric duct, after it acquires a lumen, and extends to the anus. At the present stage, number 160, the first steps in the differentiation of the pronephric chamber and duct have occurred. At the level of the 4th, 5th, and 6th somites, the primitive plate of intermediate mesoderm is thickened and its ventral mesial border is drawn slightly downward and inward. Its cells are compressed, and no cavity is present. The line of cells marking off the pronephric duct can be traced in these sections from somites 7 to 12. The lumen of this duct has likewise not yet formed. The development follows the description of Swaen and Brachet (1900) and is slightly less advanced than is figured by them in Figures 17, 18, and 19, of Plate XII.

In the angle on each side of the body opposite the first anterior somites there is a longitudinal furrow paved with columnar epithelial cells. At the intervals between somites, these cells form a conspicuous cluster. Anterior to the first somite this thickening swings dorsally and approaches the auditory sac. Whether this line of cells represents an early stage in the development of the lateral line, or whether it is simply due to other and unrelated development of the surface ectoderm, the author is unable to determine at this point.

Stage 176. O. S. U. Series.—(Incubation period, 30 days, 4 hours; 117.8 T. U.; 24 somites.) The degree of development in this stage of the brain and sense organs is not significantly different than that described in the previous stage. The cells of the brain and nerve cord are now regularly disposed throughout the length of the body along the lateral margins and are separated by a narrow line throughout the dorsal portion. The canalis centralis extends the length of the nerve cord near its floor. In sagittal sections, a mass of head mesoderm is seen in the same relative position as that described in Stage 128. It is now larger and triangular in shape. The apex of the triangle is near the superficial ectoderm on the lateral margin of the head. In the branchial region, the auditory vesicle, branchial folds and endocardium have developed to a slightly more advanced stage but their relationships are essentially the same as in the previous description. The folds of the gut rapidly diminish in extent in the esophageal region, and merge into an unfolded sheet of entoderm at the level of the 2d. somite. A minute lumen appears between the entodermal cells in the mid-line opposite the middle of the 3d. somite, and continues for the length of almost five somites. Sclerotome formation is more advanced in the anterior somites but can be traced for at least 15 somites. Temporary cavities are present in the sclerotomal masses of the first five or six somites. The primary plates of intermediate mesoderm which are the primordia of the axial blood vessels retain the position described in Stage 160, ventro-lateral to the sclerotome and dorsal to the entoderm. These

wedge-shaped masses extend in toward the mid-line particularly between the somites. From the 6th to the 9th somite level a few cells have reached the mid-line and penetrate the cavity beneath the subnotochordal rod. This condition is less distinct at other levels.

The degree of development of the pronephric chamber is only slightly more advanced than described in the preceding stage. The primordium of the pronephric duct still lacks its lumen but can be traced from somites seven to eighteen.

The ectodermal thickenings along the sides of the body can be located in sections on the side of the trunk opposite the divisions between somites backward as far as the interval between the 7th and 8th somites.

Stage 192. O. S. U. Series.—(Incubation period, 32 days, 20 hours; 119.5 T. U.; approximately 28 somites.) The mid-brain is now divided into two distinct optic lobes separated by a conspicuous Sylvian aqueduct, and the hindbrain is differentiated into the metencephalon and myelencephalon. The walls of the brain stem in this area have become thickened, and the fourth ventricle appears for the first time with this stage. The optic stalk is more constricted than described in Stage 160. The conditions through the middle of the body are the same as described for the previous stage, with the following modifications. The intermediate cell masses still lie ventral to the sclerotome on either side but are composed of a larger number of cells and hence are more prominent. More cells than before have migrated from this mass into the mid-line beneath the subnotochordal rod. There are approximately twenty-eight somites present. The primordium of the pronephric duct may be traced from the seventh to the twenty-second somite.

The tail is distinctly raised above the yolk, and the tail fold is beginning to undercut it.

Stage 208. O. S. U. Series.—(Incubation period, 35 days, 12 hours; 123.14 T. U.; 32 somites.) The fore-brain is now differentiated into telencephalon and diencephalon. The infundibulum is present here in its initial stages of development as a slight thickening beneath the floor of the diencephalon, adjacent to the point of emergence of the optic stalk. The blind anterior end of the pharynx is immediately posterior to the infundibulum. Here both the upper and lower layers of the pharyngeal wall extend laterally and are in continuity with the surface ectoderm on the side of the head. Both the hyomandibular and first branchial pouches are definitely in contact with the slightly invaginated surface ectoderm. The first branchial pouch extends diagonally from just before the auditory pit, backward and downward beneath it. Midway beneath the auditory pit the pharynx rounds up sharply into the gut which possesses a lumen for a short distance. Posteriorly, the entoderm is a highly arched layer in the mid-ventral line whose lower edges have not yet fused, and which is flattened out progressively caudad. The endocardial primordium lies as a single mass of loosely connected cells beneath the pharynx backward to the level of the first branchial pouch. It is somewhat more sharply delineated from the epimyocardial folds than described in Stage 160. The epimyocardial folds likewise are more thickened in cross-section than in the former stage.

The pronephric ducts may be traced from somites seven to twenty-two as before. There are 32 somites present. Posterior to the last somite there extends a non-segmented mesodermal mass backward to the level of Kupffer's vesicle, which lies beneath the caudal end of the notochord.

Stage 224. O. S. U. Series.—(Incubation period, 38 days, 4 hours; 125.8 T. U.; total length of embryo, 4.2 mm.; 39 somites.—Reconstruction drawing, Plate III.)

The reconstruction drawing of this stage may be directly compared with that of Stage 128, Plate II, in the first paper of this series. It is seen that the embryo has increased more than one-third its former length in the interval between these two stages. By this time it has passed through a little more than one-fourth its total incubation period, in point of time (38 days out of a total of 134 days), and one-third of its incubation period in point of thermal units (126 T. U. out of a total of 345 at hatching). Its present length of 4.2 mm. is likewise about one-third of its hatching length, (12 mm.). It is of significance that in this first third of its incubation period, every major organ system and structure present at hatching with the exception of the paired pectoral fins has been definitely laid down. The embryo at this time is clearly outlined on the surface of the yolk. It extends without torsion over approximately one-half of that surface, and its anterior end is somewhat imbedded in it. The conspicuously large brain and sense organs, particularly the eyes, indicate a precocious development in that region.

The definitive brain lobes, including the infundibulum, are established and can be distinguished in the whole mount. The nasal pit is in the form of an elliptically invaginated sac, lined with columnar epithelium, on the antero-lateral angle of the forebrain. The prominent eye possesses a well-developed circular lens centrally placed, and the optic nerve is seen to extend forward from the mesial-ventral surface of the eye to enter the diencephalon at the anterior end of the infundibulum. The head is imbedded in the yolk up to the level of the lens. Extending over the yolk laterally from this point is a sheet of extra-embryonic somatopleure shown in the drawing as a lightly stippled band.

The brain has greatly increased in width, particularly in the region of the medulla oblongata, where it is much broader than deep. This widening process has brought about a great expansion of the fourth ventricle, which is very conspicuous from the dorsal view. Triangular in shape, its area is approximately equal to that of the remainder of the brain. The choroid plexus which covers its roof is seen in the drawing to be clearly separated from the underlying nervous tissue. Laterally, the auditory sac is a rounded invaginated vesicle of columnar cells closely applied to the sides of the medulla. The medulla posterior to the auditory sac rounds up rapidly into the tubular nerve cord which is well developed and prominent in this stage and continues to the tail region. There, the nerve cord fades out into a caudal mass which is losing its embryonic character.

The process of vacuolation of the cells of the notochord which began

in Stages 128 and 144 has progressed and now is evident throughout its length. The cells as a result of this process have been greatly enlarged and the notochord has been increased in diameter. The notochord acquired its maximum length in Stage 128. It extends forward to end beneath the medulla, approximately at the anterior end of the pharynx. The anterior end of the notochord from this time on appears to be a relatively fixed point, with respect to the floor of the medulla, but the relative positions of the anterior end of the pharynx and of the infundibulum become greatly altered as development proceeds.

The foregut terminates at a point posterior to the orbit, and in contact with the underlying surface of the head region. Neither in this stage nor subsequently is there any indication of the presence of a stomodaeum. The end of the foregut is some 100 microns behind the posterior end of the infundibulum, but in later stages, these two structures come in contact with each other.

The foregut is completely folded on itself. It arches broadly laterally, and extends to the surface ectoderm. The branchial furrow is essentially an infolded portion of thickened ectoderm in the angle on the side of the head. The hyomandibular pouch is in contact with this furrow but no cleft is formed. The first branchial pouch beneath the anterior portion of the auditory sac has broken through this furrow to form an open gill cleft, in which the pharyngeal wall is continuous with the surface ectoderm. The ectoderm lines the outer end of the cleft for a comparatively short distance, leaving the remainder of the cleft lined by entoderm. A few sections posterior to the first branchial cleft, the second branchial pouch appears for the first time and extends laterally to come into contact with the lateral ectodermal plate for a short distance.

The pharynx itself does not possess a lumen, but as it rounds up into the esophagus, just behind the second branchial pouch, a lumen appears in the future gastric region. The gut at this stage is in the form of a closed tube throughout its entire length, lined with columnar epithelium. Its lumen gradually diminishes in diameter posteriorly. At the level of the 36th and 37th somites, the tubular gut terminates in a loosely organized strand of entodermal cells which marks the location of the future anus. Beyond that point, the entoderm continues as a solid strand of cells, the post-anal gut. This soon loses its identity, along with the notochord in the remains of the primitive streak. The post-anal gut overarches Kupffer's vesicle which now lacks a cellular floor above the yolk.

The heart has developed progressively beyond the condition described in the previous stage. The endocardium is clearly separated from the lateral epi-myocardial layers, and forms a single straight tube which extends beneath the anterior end of the pharynx from its anterior end to the level of the first branchial cleft. Here it bifurcates into two vitelline veins which spread laterally over the surface of the yolk. Paired dorsal aortae appear above the hymandibular pouch and extend backward to fuse in the midline beneath the notochord just beyond the level of the second branchial pouch. The single dorsal aorta may be traced from this point backward to the level of the eighth somite.

More caudally, its outline is lost in the undifferentiated intermediate cell mass in the median line from which it arises.

In order to avoid complexity no attempt was made to place either the somites or the pronephric tubules and ducts on the reconstruction drawing of this stage. The somites number 39 pairs, and extend from just posterior to the auditory sac, as before, throughout the body, to a point opposite the anterior end of Kupffer's vesicle. Behind the last somite, the mesoderm continues as an undivided mesodermal mass, which terminates in the primitive streak. The myotomes of the first anterior six somites possess myofibrils. The pronephric chamber possesses a distinct cavity opposite the fifth somite. The pronephric ducts extend backward to the anal region, and possess a lumen in their anterior portion. The pronephros is probably functional from this time to hatching.

The tail region is seem to be distinctly raised off the surface of the yolk, and to be rimmed in the median line by a continuous fin fold.

Developments Occurring Between Stages 228 and 400

Stage 272. O. S. U. Series.—(Incubation period, 46 days, 4 hours; 133.78 T. U.; 49 somites.) The liver appears for the first time in this stage. It is a ventral evagination from the mid-gut, at the level of the sixth somite.

Stage 288. O. S. U. Series.—(Incubation period, 48 days, 16 hours; 136.44 T. U.; 52 somites.) The pre-auditory or branchial sense organ placode is now separated from and independent of the auditory vesicle. The 3rd and 4th branchial pouches are present in succession behind the branchial cleft. Myofibrils have formed in the somites throughout the middle of the trunk. In this same region the dorsal aorta is conspicuous, but devoid of blood cells. Below it lies a large intermediate mass of cells which constitute blood islands. From this mass the axial vein and the erythrocytes of the embryonic blood supply become differentiated. The embryonic coelom is conspicuous also at this level. The gut is surrounded by splanchnopleural folds and it is suspended by a dorsal mesentery.

Stage 304. (Incubation period, 51 days, 12 hours; 139.1 T. U.; 56 somites.) At this stage the pectoral fins appear as lateral masses of undifferentiated mesenchymatous tissue, covered by a thin layer of squamous epithelium. They are small, rounded, lobate structures extending laterally from the body just posterior to the head region. Their faint outlines in surface views of whole mounts are seen at this stage with difficulty, but by Stage 400 they are clearly visible. They apparently arise as outgrowths from the body wall, with which they are closely associated, rather than from the head mesoblast as described by Wilson in *Serranus*.

Stage 320. (Incubation period, 54 days, 4 hours; 141.76 T. U.; 62 somites.) For the last several stages described, the cells in the anterior portion of the notochord have been undergoing vacuolation progressively caudad. As a result, the protoplasm of the notochordal cells in the anterior half of the embryo has been reduced to a thin peripheral layer. For the first time in the present stage, the notochord

is surrounded by a hyaline sheath which takes a deeper stain than the surrounding tissue. From this incipient condition, this hyaline cartilaginous sheath becomes increasingly thick and more rigid as development proceeds. Beneath the notochord, the dorsal aorta may be traced throughout the length of the body into the tail region, where the caudal vein runs beneath it. The subintestinal vein is visible beneath the intestine for the first time. The gut possesses a distinct lumen throughout its length. The splanchnopleural folds, which were seen to surround the mucosal layer of the primitive gut wall in Stage 288, have apparently split into a double layered condition. These two layers constitute the primordia of the muscular wall of the intestine and its peritoneal covering. Posteriorly, the gut penetrates the ventral fin-fold of the body wall and ends at its lower margin. The vent is virtually closed. A few sections in advance of it the pronephric ducts unite and enter the dorsal wall of the gut at a point which represents the roof of the cloaca.

The fin-fold around the tail is composed of a folded layer of epidermis. Interrupted at the vent, it continues forward as far as the body is free from the yolk.

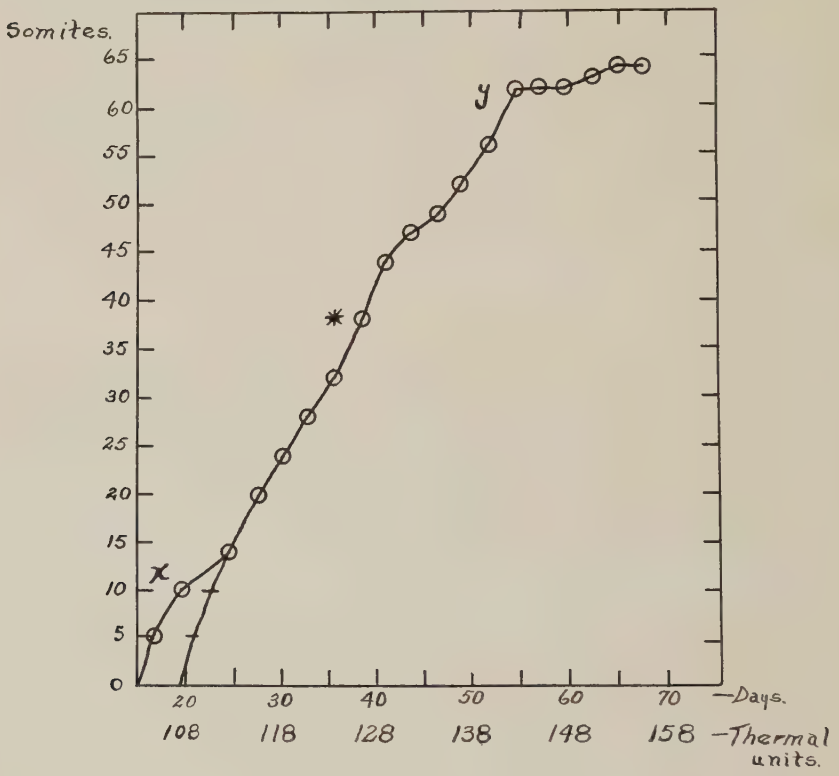
Stage 352. (Incubation period, 59 days, 12 hours; 147.08 T. U.; 62 somites.) The pronephric chambers on either side at the level of the 4th and 5th somites have become enlarged and have migrated farther than previously toward the midline. Their mesial surfaces are infolded and enclose short branches of the dorsal aorta to form a simple glomerulus. The chamber ends in a blind sac at the level of the sixth somite.

Stage 368. (Incubation period, 62 days, 4 hours; 149.74 T. U.; 64 somites.) With this stage, the full adult number of somites is present in the embryo. At no time in the remaining stages of this series has a greater number of somites been found. The number, then, of sixty-four somites may be regarded as the hatching number, and the definitive number for this species. It is of interest to note that the complete number of somites is differentiated in the whitefish before the embryo has completed the first half of its incubation period.

Once the formation of the paired somites is initiated, an increase in their number apparently occurs at a rate directly proportional to the number of thermal units to which the embryo has been subjected. In the foregoing descriptions, the length of the incubation period of each stage in this series is given in terms of both time and thermal units following fertilization. It is seen from these data that at Stage 112, no paired somites were present. By Stage 120, five somites were present and the sixth was partly formed. This embryo had undergone 105 thermal units of incubation.

The complete number of somites was acquired when the embryo had been subjected to an incubation period of 150 Thermal units. When the numbers of somites for the different stages through this part of the embryonic period are plotted on a graph as ordinants and the thermal units of incubation for these same stages are plotted as abscissae, the resulting values form practically a straight line curve. (See Graph No. 1.) This may be interpreted as expressing a direct

relationship between these two sets of factors, the number of somites increasing at a rate directly proportional to the sum of the time and temperatures to which the embryo has been exposed. The thermal units have been calculated from daily temperature and time charts of the incubation period, following the method described in the first paper of this series. If the thermal unit is a valid criterion for deter-



GRAPH No. 1. The relation between the age of the whitefish embryo, expressed in terms of days and thermal units of incubation, and the number of somites present. The small circles indicate thermal unit values. The symbol x indicates the period of initial somite formation; the asterisk, *, the stage when the heart and pronephric tubules becomes established; the symbol y, the appearance of definitive axial blood vessels.

mining comparable stages in different series of embryos, then embryos of the same age in number of thermal units will have a similar number of somites.

The curve is actually not straight but rather a wavy line. There are three periods in which the growth increment is greater than in intermediate ones. The first, indicated by the letter x, on the graph, is an initial period of rapid growth, when the first few somites are being laid down. Then the rate is gradually retarded up to about 125 Thermal

units of incubation. A second period (*) of more rapid growth is then initiated. It is of interest to note that at this time two significant events occur. The heart is formed as a distinct tube, but devoid of blood cells, and the pronephric ducts for the first time acquire their lumen, and extend to the anus. Both the circulatory and excretory systems probably begin to function at this time. The probability that these systems influence the growth rate of the somites is strengthened by the fact that in the amniotes the growth rate of the embryo is influenced by them in a similar manner (Schmalhausen, 1927). The third cresty in the curve occurs just after the dorsal aorta and the axial vein become distinguishable throughout the length of the embryo, and are filled with blood.

The curve now bends rapidly to the right. The formation of additional somites is here apparently greatly retarded by inhibiting factors which operate to prevent the formation of more than sixty-four somites in this species. The embryo hereafter possesses this same number of somites. The curve for these later stages then would be a straight line.

The author is unable to say just how typical this curve with its fluctuations is for the species as a whole. The number of embryos included in this study is too few to warrant the deduction of very definite conclusions. Several embryos for each stage must be examined to determine the degree of variation within each stage before the relationship between these various factors may be stated with any degree of certainty.

In the myotomal region of the anterior somites the myofibrils have a beaded appearance, due to the presence of alternate light and dark bands. These collectively, of course, give the appearance of cross-striations to these fibres.

Stage 400. (Incubation period, 67 days, 12 hours; total length of embryo, 8 mm.; 64 pairs of somites; 155.06 T. U.) (Reconstruction drawings, Plate IV.)

Despite the fact that the embryo at this stage has only completed one-half of its incubation period, it has now acquired two-thirds of its length at hatching (12 mm.) and the complete number of somites which it will possess at that time—sixty-four.

The embryo has been forced by the constant shrinking of the yolk sac to assume a curled position upon it. The tail which was becoming free from the yolk in Stage 224 (Plate III) has now become bent back on the body to form an almost complete circle on the surface of the yolk at this stage. This condition makes it impossible to reconstruct the embryo on a plane surface drawing in the coiled portions of the body. To do so would necessitate a drawing of one part of the coil seen behind or through the other, or viewed at an angle, which latter would introduce errors in perspective. It was found to be impossible to straighten the embryo from its curved position. Hence simply the anterior portion of the body, back to the first sharp curve, has been included in these drawings.

By a comparison of Stage 400 with Stage 224, it is seen that several noteworthy changes have occurred. During this interval the embryo has approximately doubled its total length, from 4.2 mm. to 8 mm. There has

been a great lateral growth of the body, especially in the head region. The depth of the head in the two stages is about the same; but seen from the dorsal surface (not shown in the drawings) the body and head, including the brain, have greatly expanded laterally. The medulla in Stage 400, side view, appears thinner and more shallow than in Stage 224. This is actually the case, but the thinning process is brought about by a lateral growth of the medulla which has approximately doubled its former width. The cavity of the fourth ventricle above it has also greatly expanded, and the membranous choroid plexus is a prominent landmark. There has been a correspondingly great lateral growth of the midbrain, and the differentiation of the metencephalon. The latter is now a thin transverse plate separated from the mesencephalon by a transverse fissure.

In Stage 224, the nasal pit is terminal on the forebrain. In Stage 400, there has been a downward and backward growth of the forebrain and the infundibulum, carrying the nasal pit with it until it comes to lie ventrally.

The expansion of the lobes of the brain, and their further differentiation into their definitive parts, has brought about a thinning of their walls, leaving cavities within. In Stage 224 no expanded cavities traceable in a drawing were present. As a result of the backward and under growth of the forebrain, the infundibulum is very prominent, and extends to a point in close proximity to the anterior end of the fore-gut. This growth has also carried the eye with it in its backward migration with the result that the eye and the ear are in much closer proximity to each other than formerly. It will be seen that the changed position must be due to the shifting of the forebrain, since the relative position of the ear to the medulla and to the anterior end of the notochord remains essentially the same as in Stage 224.

The foregut ends in the same relative position as in the latter stage. There is no visible connection seen between the foregut and the infundibulum, nor any semblance of a stomodaeum present.

The branchial pouches are broadly extended laterally. The hyomandibular pouch is more restricted in extent than in earlier stages. The first branchial cleft is the only one open at this stage. Branchial pouches II, III, IV, all lie posterior to the otic vesicle. They are separated from each other by an undifferentiated mass of head mesoderm which comprises the visceral arch. The pharynx has grown very broad here in comparison with the condition shown on the previous drawing, Stage 224, Plate III, in correlation with the lateral growth of the head. From the drawing of the median sagittal section, it is seen that there is no lumen present in the pharynx, and that it does not appear anterior to the gastric region, which is an expanded area at the level of the pectoral fin. Here the columnar epithelium is well differentiated. Surrounding this part of the gut, the liver is forming as an elongated glandular outgrowth closely applied to the rounded gut wall.

The tubular heart is considerably larger than in Stage 224. It has become elongated and now extends backward to the level of the esophagus, and bends in a U-shaped loop away from the median line. Only the two ends of the loop pass across the median line. The

heart is now suspended by the mesocardium within the pericardial cavity. The vitelline veins are large and are filled with erythrocytes. The short ventral aorta leads forward from the heart into the aortic arches which pass laterally over the pharyngeal folds.

The auditory vesicle is gradually undergoing differentiation. Its outline is no longer smoothly circular, but somewhat irregular, indicating three bulbous prominences, which will develop later into the ampullae at the bases of the semicircular canals.

The preauditory sensory placode was described in Stage 288 as having separated from the auditory vesicle but lying immediately anterior to it. Since that stage, this placode has apparently migrated forward. It now lies on the side of the head dorsal to the posterior curvature of the orbit and anterior to the level of the hyomandibular pouch. It is a single, elongated sensory patch. Its cells have become elongated and somewhat clustered.

The first anterior pair of somites lies immediately behind the auditory vesicle. These 64 pairs of somites are clearly seen in the whole mounts. Their cells are differentiated and contain striated myofibrils. Beginning with the fifth or sixth pair, each somite has been divided by a horizontal constriction into a dorsal and lateral portion. These muscle masses are probably capable of contraction to cause bodily movements.

The pronephric chambers each have a single glomerulus on their mesial border, and the pronephric tubules enter the dorsal portion of the cloaca as described in Stages 320 and 352.

The paired pectoral fins which were previously described as first appearing in Stage 304 are now definitely raised up from the surface of the lateral somatopleure and possess a median longitudinal fin fold. They are subtriangular in shape and lie opposite somites III to VII.

SUMMARY

This paper is the second of a series of three papers on the embryology of the whitefish. The author's purpose is to locate the incipient stages in the development of each of the organ systems and to trace their general development in this particular series of embryos.

It is seen from the descriptions of Stages embodied in this paper that every line of development in the whitefish embryo is well established by Stage 400, which marks the end of the first half of the incubation period of this series in terms of time and temperature under normal hatchery conditions.

Since the closure of the blastopore, differentiation and growth have converted the primitive embryo into one of distinct fish-like form. It is now completely coiled on the yolk, and is two-thirds its hatching length. The tri-lobed brain has developed its definitive regions, and the nose, eye and ear are advanced well beyond the vesicular condition.

The differentiation of the organs derived from the mesoderm scarcely begins before the closure of the blastopore. The growth of the notochord forward, the vacuolation of its cells, and its investment by a cartilaginous sheath has been traced. The increase in the number of somites to the full number, and the differentiation within the muscle masses of striated myofibrils has been described. The development

of the heart, axial blood vessels, and definitive blood cells has brought the circulatory system up to a stage where it is probably functional. The same is true of the pronephric kidneys which are seen to develop concurrently. The visceral arches, pericardium and the coelomic cavity are all well established.

The entoderm comprised an unfolded primary germ layer at the time the blastopore closed. Since that stage, the gut has become a closed tube throughout its length. The first of the branchial pouches has broken through the pharyngeal wall to form a cleft and the remaining three pouches are well defined. The liver and the lumen of the gastric region have developed. The anus has not ruptured through the ventral fin fold.

The primitive streak, so prominent when the blastopore closed, has gradually shortened, and its substance has contributed to the formation of structures in the tail region. Kupffer's vesicle, formerly so prominent, has disappeared in the region of the anus.

Thus the period of organogenesis closes. Before the embryo may emerge from its egg shell, growth and further differentiation must bring it to the hatching state. The outstanding phases in this later development of the whitefish will be discussed in the paper which is to follow.

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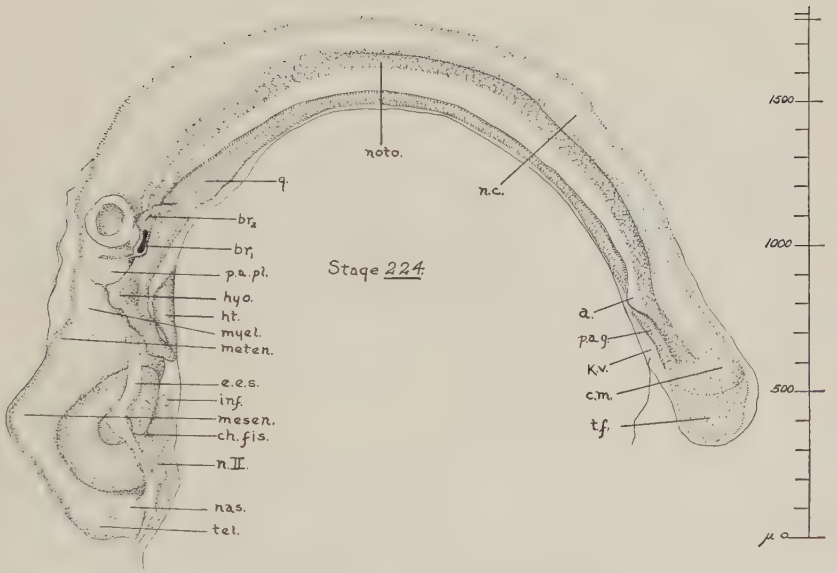
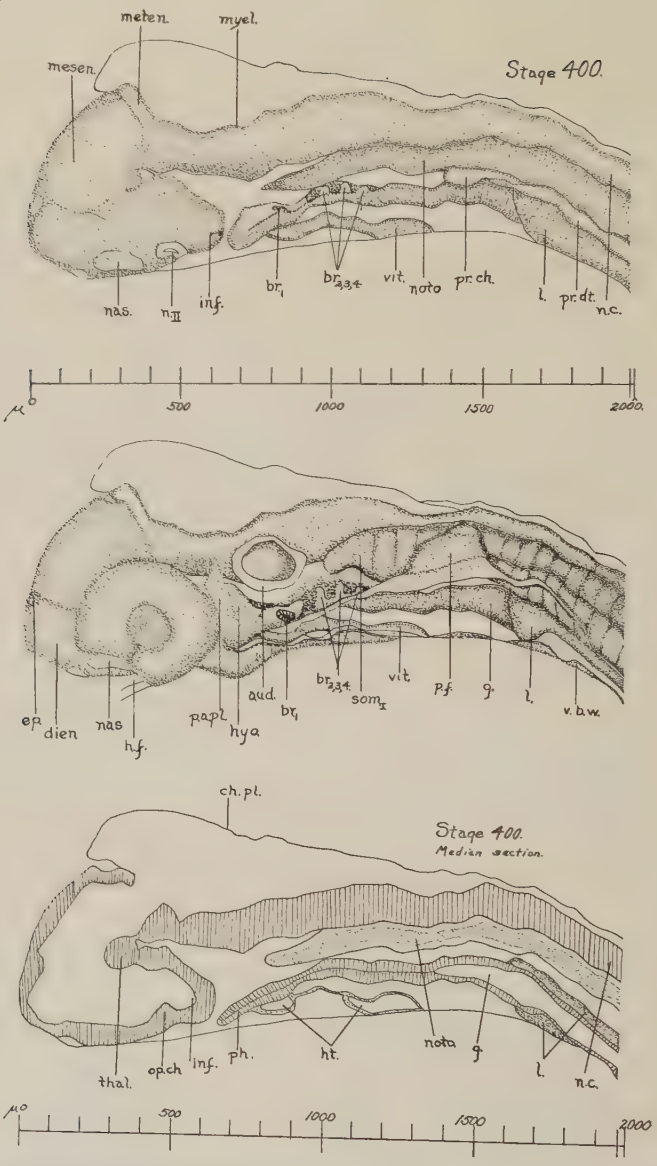
ABBREVIATIONS USED IN PLATES III AND IV

a.....anal region
aud.....auditory vesicle
br. 1.....first branchial cleft
br. 2, 3, 4..branchial pouches
ch. fis.....choroid fissure
ch. pl.....choroid plexus
c. m.....caudal mass, or primitive streak
dien.....diencephalon
e. e. s.....extra-embryonic somatopleure
ep.....epiphysis
g.....gut
h. f.....head fold
ht.....heart
hyo.....hyomandibular pouch
inf.....infundibulum
K. v.....Kupffer's vesicle
l.....liver
mesen.....mesencephalon
meten.....metencephalon
myel.....myelencephalon
n. II.....optic nerve
nas.....nasal pouch
n. c.....nerve cord
noto.....notochord
op. ch.....optic chiasma
p. a. g.....post-anal gut
p. f.....pectoral fin
ph.....pharynx
p. a. pl.....preauditory placode
pr. ch.....pronephric chamber
pr. dt.....pronephric duct
som. I.....first ant. somite
tel.....telencephalon
t. f.....tail fold
thal.....thalamus
v. b. w.....ventral body wall
vit.....vitelline vein



Reconstruction drawing of Stage 224, O. S. U. series, in natural position over the yolk. Length of embryo, 4.2 mm.; 39 somites.



Reconstruction drawings of Stage 400, O. S. U. series, anterior end of embryo. Embryo length, 8 mm.; 64 somites. This stage marks the end of the first half of the incubation period.

Fig. a (upper.) Reconstructed at the level of the brain surface, to the left of the median line.

Fig. b (center.) More lateral than Fig. a, showing sense organs, paired somites, pectoral fin, etc.

Fig. c (lower). Median sagittal section.

All three figures are drawn at the same magnification.

A PRELIMINARY STUDY OF THE LENGTHS OF THE OPEN VESSELS IN THE BRANCHES OF THE AMERICAN ELM[1]

FRANKLIN G. LIMING

Results obtained from previous studies by the writer, using basic dyes and the spores of *Graphium ulmi* (the fungus causing the Dutch Elm Disease) in elm branches, and other workers, using mercury and various dyes in apple, oak and other woody stems, indicate that in a given species the length of the vessels in young stems is less than in older stems and that in stems of the same age there is a close correlation between the length of the vessels and the length of the stems in which they occur. As a preliminary study of the development of the water conducting system of the American elm (*Ulmus americana* L.) about 1,100 vessels in branches of different ages and lengths were measured to ascertain the relationship which exists between the length of the vessels and the age and length of the branches in which they were located.

The branches used in this study were taken from the upper part of the crowns of young elm trees during the month of February, 1932. The trees were about 11 m. high and about 15 cm. in diameter 1 m. from the ground. Only those branches which had made what appeared to be a "normal" growth in length during the last four years were used. Owing to the fact that the length of the terminal growth on the same branch varies from year to year and on different branches within the same year the length of the portion of the branch to be used was determined by yearly segments and parts of yearly segments rather than by definite fixed lengths.

In making the determinations the basal ends of branches of the desired age were cut square across with a sharp knife and connected to the lower end of a mercury column by means of a piece of "high pressure" rubber tubing. An arbitrary height of 120 cm. of mercury was chosen as a source of pressure. Mercury under this pressure will pass through any unobstructed opening over 1.3 μ in diameter with which it comes in contact. The lumina of the water conducting vessels in elm branches are

[1]Papers from the Department of Botany, The Ohio State University, No. 348.

well over 1.3 μ in diameter. With the cut end of the branch in contact with the mercury and the rest of the branch held in a horizontal position, pieces about 0.5 cm. long were cut successively from the unattached end of the branch until the mercury was observed to pass through the remaining portion of the branch in one vessel. The high surface tension of the mercury causes it to take the form of small spherical droplets as it first emerges from the branch, thus making its presence and exact location easily determined. The fact that the mercury passes through the branch indicates that there is one opening 1.3 μ or more in diameter extending the entire length of the remaining portion of the branch. Since the mercury does not pass through the branch before the last piece is cut off the opening must terminate in that section. Therefore the vessel either terminates at an end wall in that section or is plugged by some mechanical obstruction such as tyloses, gums, etc. Just how far the vessel or opening being measured extends below the point at which the mercury was attached can not be determined. Thus it is evident that the measurements obtained by the above method do not necessarily represent the full length of the vessel but only the length of the branch from the point of attachment through which there is a continuous opening 1.3 μ or more in diameter. The term "open vessel" as used in this paper refers to such openings. After the longest open vessel in a branch was measured the length of other open vessels in the same branch was ascertained by cutting off additional pieces, watching for the appearance of other mercury droplets, and then measuring the length of the portion of the branch through which the mercury passed in the other vessels.

The longest 15 vessels in all the branches were located in the outside annual ring. When the branches were cut back to such a length that the mercury passed through them in the vessels in the inner annual rings the amount of mercury coming through the open vessels in the outer annual ring was so great that it was impossible to determine the exact number of vessels through which the mercury was passing in the inner annual rings. The passage of mercury through the vessels in the outer ring was avoided by disconnecting each branch from the mercury column after the vessels in the outer ring had been measured and carefully removing the wood of the outer annual ring of each branch at the basal end so that when the branch was

again connected to the mercury column the vessels in the outer annual ring were not in contact with the mercury. With the branch connected in this way the length of the open vessels in the inner annual rings was measured. In no instance was the mercury observed to pass from the vessels in any one annual ring to the vessels in any adjacent annual ring. This indicates that there were no openings 1.3 μ or more in diameter connecting the open vessels in any two annual rings.

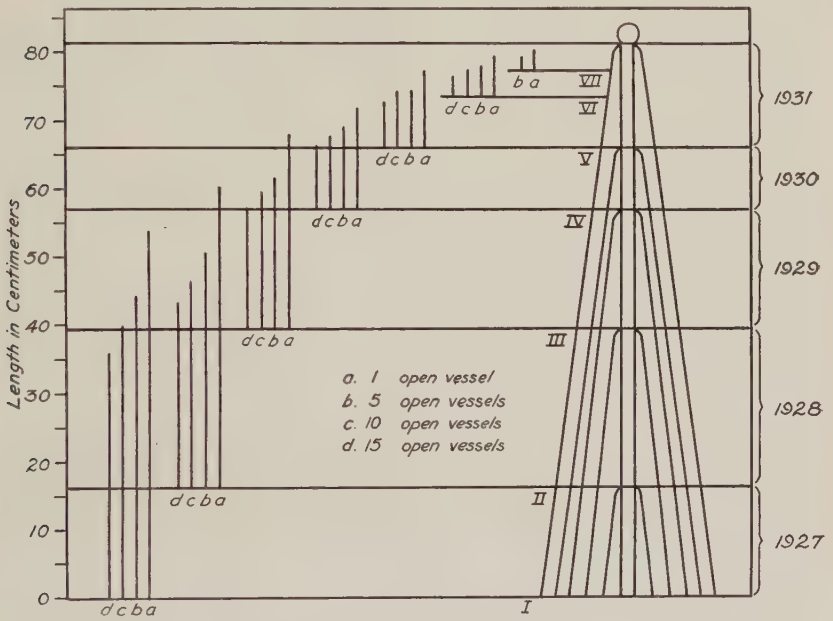


FIG. 1. The average length of the last five yearly segments of the branches of American elm and the average length of the longest portion of the branches through which mercury passed in 1, 5, 10 and 15 open vessels in the spring wood of the 1931 annual ring from the points I, II, III, IV, V, VI and VII.

The above method is suitable only for branches less than 3 cm. in diameter. The larger branches used in this study were connected to the mercury column with an "injection jet" designed by The Davey Tree Expert Co. In this way the mercury is introduced into the branch through a hole bored into the side of the branch instead of at the basal end as in the smaller branches. Instead of the small 0.5 cm. pieces, sections 5 to 10 cm. long were cut from the end of each branch until the mercury passed through the remaining portion of the branch.

Figure 1 represents diagramatically the average length of

the last five yearly segments of the branches used and the average length of the measured open vessels in the spring wood of the 1931 annual ring in these segments. Mercury was applied at the points I, II, III, IV, V, VI, and VII in the various branches and forced towards the terminal end of each branch. The length of the portion of the branch and the number of vessels in which mercury would pass through the branch was found to be the same regardless of which end of the branches was attached to the mercury. The lines a, b, c, and d represent the average length of the branches through which the mercury passed in 1, 5, 10, and 15 vessels respectively from the point of attachment.

The open vessels measured in this study ranged in length from 0.5 cm. to 5.5 m. The shortest open vessels measured were located just below the terminal buds and the longest open vessels were located in the spring wood of the 1931 annual ring in the lower part of the trunks.

There is a very definite and consistent correlation between the length of the open vessels in the spring wood of the 1931 annual ring and the length and age of the branch in which they are located. In general the length of the longest portion of the branch having five open vessels extending through it is about 55% of the total length of the branch. The length of the open vessels is more closely correlated with the length of the branch, and with the age of the branch in so far as it affects the length of the branch, than with the age alone. For example, the open vessels in branches of the same age and length were found to be about the same length while those in other branches of twice the age and double the length were found to be about twice as long. However, if the branches were all the same age and some of them were twice as long as the others the vessels in the longer branches were not twice as long as those in the shorter branches but only about 90% to 95% longer. Also, if the branches were all the same length and some of them were one year older than the others the vessels in the older branches were found to be from 5% to 10% longer than the vessels in the younger branches.

In the inner annual rings, the vessels or openings through which the mercury passed were limited largely to the summer wood of each ring and were only from 5% to 10% as long as those in the spring wood of the outside ring in the corresponding segment of the same branch. Microscopic examination showed

that there were many tyloses present in the spring vessels in these inner annual rings. The actual length of the vessels in the spring wood of the inner annual rings may be the same as those in the outside ring of the corresponding segment, but the passage of mercury was prevented in some way, probably by the presence of tyloses, gums or other mechanical obstructions. The fact that mercury fails to flow for more than short distances through the vessels of these inner annual rings does not, of course, necessarily mean that the movement of water through such vessels is similarly restricted. A more detailed study dealing with the structure and time of formation of these obstructions is now in progress.

SUMMARY

1. The length of 1,100 open vessels in American elm branches of different lengths and ages was ascertained by forcing mercury through the branches under a pressure of 120 cm. of mercury.

2. There was found to be a close correlation between the lengths of the open vessels in the spring wood of the 1931 annual ring and the lengths of the branches in which they were located. The length of the longest five open vessels extending through the branches, from any point on the branch, towards the terminal end was found to be about 55% of the distance of that point from the terminal end of the branch.

3. There was also a close correlation between the age of the branches and the length of the vessels in them. This correlation was found to be largely due, not directly to age alone, but to the increase in length of the branches resulting from the increase in the age of the branches.

4. There was no evidence that the mercury passed from the vessels in any one annual ring to the vessels in any other annual ring.

5. In the inner annual rings, the vessels or openings through which the mercury passed were limited largely to the summer wood of each ring and were only from 5% to 10% as long as those in the corresponding segment in the 1931 annual ring.

The writer wishes to acknowledge the assistance received from Dr. B. S. Meyer and Dr. W. H. Camp, of the Department of Botany, Ohio State University, and Dr. O. N. Liming, of the Dutch Elm Disease Control Office, U. S. D. A., and to thank the Davey Tree Expert Co. for the use of certain apparatus used during the course of the study.

NOTES ON ZYGNEMATACEAE[1]

E. N. TRANSEAU

Further study of certain groups of species of the *Zygnemataceae* has suggested the desirability of raising several previously recognized varieties to the status of species, as follows:

Zygnema ornatum (Li) comb. nov.
(=*Z. collinsianum* Transeau var. *ornatum* Li, 1933).
Not uncommon in the states from Alabama to Oklahoma.

Spirogyra suecica nom. nov.
(=*S. varians* (Hass.) Kuetz. var. *gracilis* Borge, 1923).
Known in the United States from Iowa, Ohio and Florida.

Spirogyra labyrinthica nom. nov.
(=*S. daedalea* Lagerheim var. *major* Hirn, 1913).

Spirogrya distenta nom. nov.
(=*S. decimina* (Mull.) Kuetz. var. *inflata* Fritsch, 1921).
Known in the United States from Illinois and Ohio.

Spirogrya discreta nom. nov.
(=*S. inflata* (Vauch.) Rab. var. *foveolata* Transeau, 1914, which is not a synonym of *S. foveolata* Czurda, 1932).

Spirogyra teodoresci nom. nov.
(=*S. varians* (Hass.) Kuetz. var. *minor* Teodorescu, 1908).
Widely distributed in the eastern United States.

Spirogyra suomiana nom. nov.
(=*S. punctata* Cleve var. *major* Hirn, 1895).

Spirogyra crassiuscula (W. & N.) comb. nov.
(=*S. maxima* (Hass.) Wittr. f. *megaspora crassiuscula*, W. & N. 746).
Diam. vegetative cells 145–170μ, spores 120–150μ × 85–100μ.

Spirogyra megaspora (W. & N.) comb. nov.
(=*S. maxima* (Hass.) Wittr. f. *megaspora crassa*, W. & N. 745).
Diam. vegetative cells 170–200μ, spores 135–170μ × 95–120μ.

Sirogonium tenuius (Nordstedt) comb. nov.
(=*Spirogyra stictica* (Eng. Bot.) Wille var. *tenuior* Nordst., 1882).
Originally described from the Argentine, and recently collected by C. E. Taft in Oklahoma.

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[1]Papers from the Department of Botany of the Ohio State University, No. 347.

NOTES ON CERTAIN OHIO OAKS[1]

W. H. CAMP

Although the present study of the Ohio oaks is by no means complete, it is thought best to call attention to several features of the work at this time.

In the first place, certain corrections should be made in the nomenclature:

Quercus maxima (Marsh.) Ashe.—(*Q. rubra* L.)—Red Oak.
Quercus rubra L.—(*Q. tribola* Michx.)—Spanish Oak.
Quercus montana Willd.—(*Q. Prinus* L.)—Rock Chestnut Oak.
Quercus Prinus L.—(*Q. Michauxii* Nutt.)—Cow Oak.

Although the Cow Oak (*Q. Prinus*) is not certainly known to occur in Ohio it is here listed to indicate the disposition of that species. It is unfortunate that the above specific names, known so long and almost universally used, must be changed, but the shift is necessary to keep the nomenclature correct.

One of the problems in working with the oaks is the differentiation between certain species, and hybrids between other species or their aberrant forms. A case of this is a collection made by Dr. Kellerman in Gallia Co., in 1901, which he took for a hybrid (*Q. palustris* X *Q. velutina*). The present writer feels that this is not the case, rather, that it is an extremely aberrant form of the Scarlet Oak (*Q. coccinea* Muench.), although a careful examination of the specimen, together with Dr. Kellerman's field notes, seem to indicate that it is Hill's Oak (*Q. ellipsoidalis* E. J. Hill). This last species is not known farther east than northwestern Indiana.

Another case of this type is Schneck's Oak (*Q. Schneckii* Britt.). This species, typically southern in its distribution, but occurring fairly commonly along the Ohio River as far north as Indiana, is recorded for Ohio by Small (Man. S. E. Flora, 1933) and specifically for the Cincinnati area by Braun (Amer. Midland Nat., Vol. 15, p. 30, 1934). It is, however, represented in the O. S. U. Herbarium by only two collections, both of them from Franklin County. It is hoped that subsequent collecting in southern and southwestern Ohio will reveal intermediate stations, but until then it is doubtful if Schneck's Oak, in its true form, occurs in central Ohio.

Alexander's Oak (*Q. Alexanderi* Britt., Man. Fl. N. St. and Can., p. 336, 1901) has been recognized by Trelease as a form of the Chestnut or Yellow Oak (*Q. Muhlenbergii* f. *Alexanderi* Trel., Mem. Nat. Acad. Sci., Vol. 20, p. 111, 1924). Field studies in various areas where this species is common indicate that it has a definite genetic constitution and

[1]Papers from the Department of Botany, The Ohio State University, No. 349.

with its characteristic broadly obovate leaves should be considered a valid variety. The present writer therefore proposes the combination **Quercus Muhlenbergii** var. **Alexanderi.**

One of the most interesting features of the present work has been a special study of the Northern Red Oak—Gray Oak complex. If the Gray Oak (*Q. borealis* Michx. f.) is to be considered as separate from the Red Oak (*Q. maxima* (Marsh.) Ashe.) then it is not uncommon, being known from at least twelve counties, mainly within the eastern half of Ohio. It is, however, the opinion of the writer that the two are not distinct but only two extremes of the various possibilities within the genetic range of the species, in which case our ordinary Red Oak would return to the earlier name, *Q. borealis* var. *maxima* Sarg. A statistical study of the variations within this particular group will be considered in a later paper.

BOOK NOTICES

Heat

This is a book suitable for use in a two-year course in physics such as is given at Massachusetts Institute of Technology, and to be taken simultaneously with a course in differential and integral calculus. The calculus is consequently used, at first in a small way, but gradually more and more, to treat the usual topics in statics, dynamics, and hydrodynamics.

The reviewer feels that the M. I. T. is to be congratulated that they find it possible to give a course in general physics where such a book may be applicable. This is, however, not generally the case in American colleges and universities, and it would seem that the book would have a rather limited field of application.

—HAROLD H. NEILSEN.

Introduction to Mechanics and Heat, by N. H. Frank; xiv + 339 pp. New York, the McGraw-Hill Book Co., 1934.

Abnormal Behavior and its Explanation

After a consideration of the question as to what constitutes abnormality, without a satisfactory answer, the authors discuss sensory and motor disorders, theories of a number of functions which they assemble under the head of the association mechanism, and finally desires, feelings and emotions, sleep, dreams and hypnosis. Thus the first two-thirds of the book is devoted to a discussion, often very sketchy, of common functions and the particular changes the physician often sees in them which follow trauma, shock, infection, etc. Two chapters treat the organic and functional psychoses and the remainder of the book consists of short chapters on the psychoneuroses, mental deficiency and superiority, and psychotherapy.

The authors have "written for advanced students in psychology, pre-medical and medical students who desire more psychological information." In a foreword Professor Knight Dunlap believes that this book "signalizes the beginning of the scientific era in abnormal psychology." There are indexes of subjects and authors and a bibliography of 313 titles.—S. RENSHAW.

Textbook of Abnormal Psychology, by R. M. Dorcus and G. W. Shaffer; xii + 389 pp. Baltimore, The Williams and Wilkins Co., 1934.

Features in the Architecture of Physiological Function

The author takes the stand of those who regard a phenomenon as more likely to have a significance than not. He is willing to help take the burden of discovering what the significance may be. He admits the possibility of accidents in nature, but prefers to avoid the responsibility of proving all phenomena to be accidental.

As to the manner of describing one set of conditions prerequisite to new developments in physiological function, the distinction between a purely teleological attitude and one leading through descriptive analysis is drawn on the quotation, "The stage is set before the play commences."

The book is built on the Dunham Lectures given at Harvard in 1929. An easy, fluent atmosphere characterizes the presentation of the many physiological facts on which the book is constructed. The physiological processes are discussed as following principles of function rather than proceeding from mere organ structure or chemical formulae. The stability of the internal environment compels the principle of storage of materials and of integration in adaption. This concept leads through the material of the chapters with the description of the parallel mechanisms that may function in integrative processes as well as in antagonistic responses.—R. G. SCHOTT.

The Architecture of Physiological Function, by Joseph Bancroft. x + 368 pp. New Yowk: The MacMillan Company; Cambridge, England: at the University Press, 1934.

Entomological Equipment and Methods

In his new book, "A Manual of Entomological Equipment and Methods," Professor Peterson has done for the teacher and research worker what each has wanted to do for himself but for which he has had neither the time nor the necessary reference material. It is a most excellent collection of diagrams of experimental equipment and apparatus used by entomological workers in every phase of the subject. The diagrams are completely labelled and references are given to the sources. They are grouped in a system of classification based upon use such as: Insectaries; Cages; Collecting, Killing and Sampling; Traps; Behavior Equipment; Weather Recording Instruments; Thermocouples; Thermostats; Cabinets; Insecticide Testing; etc. The plates are a bit crowded, but very clear and complete.

The manual also contains brief discussions, convenient conversion tables for temperature, humidity, weights and measures, and author and subject indexes. It is a book that no entomologist can afford to be without, being full of suggestions for methods of research and apparatus construction which with the references will save many days of tedious labor.

The work is lithoprinted, contains 138 plates and is durably bound in cloth.
—D. F. MILLER.

A Manual of Entomological Equipment and Methods, by Alva Peterson. Ann Arbor, Michigan: Edwards Brothers, 1934. $3.75.

Theoretical Physics

This book may unambiguously be termed one of the most enjoyable publications by McGraw-Hill in their International Series. It contains brief, yet complete accounts of the most important problems in theoretical physics, emphasizing those items in classical physics which lead directly to the modern quantum aspects. The first two chapters concern themselves about the mathematical equipment necessary to cope with physical problems; fifteen chapters are devoted to problems in analytical mechanics and hydrodynamics. Eleven chapters are given to discussions of heat flow, potential theory, electromagnetic phenomena and optics while the remaining fifteen chapters concern themselves with atomic and quantum phenomena.

In addition to a clear exposition of the subject matter, a set of problems supplements each chapter, a feature whose value cannot well be overestimated.

Like other books in this series, it is durably bound in green cloth, and printed in large clear type. It is a book sincerely to be recommended for use in college classes, and is an asset to any physicist's library.—HAROLD H. NIELSEN.

Introduction to Theoretical Physics, by J. C. Slater and N. H. Frank. New York, the McGraw-Hill Book Co., 1933.

Physics and Geology

This interesting manual, which follows Snyder's "Earth History," consists of 20 exercises, the first eleven covering Physical Geology, while the last nine cover Historical Geology. Each exercise is accompanied by suitable blank pages which are intended to be removed, and when "graded," returned to the manual and bound (suitable holes being provided). There are 91 exercise sheets and four cross-section sheets, all numbered and punched for replacing. The rest of the book is made up of explanatory text and assignments for completing the exercises.

It is refreshing to pick up a laboratory manual which uses the most recent, as well as the older, topographic and geologic maps, carefully selecting those which best exemplify the case to be studied. It is a pleasure to recommend this manual to teachers of geology. How widely used it will become remains to be seen. Many teachers have wisely tried to take advantage of local areas for these laboratory studies, but needless to say, good examples of the various areas are not available locally in most cases. To the student it is a convenient and satisfactory method of procedure. The authors have done a careful piece of work and the publishers have been equally careful. We hope it meets with success, but wish it could be sold for half the price.—WILLARD BERRY.

A Laboratory Manual of Physical and Historical Geology, by Kirtley F. Mather and C. J. Roy; xiv + 302 pp. New York, D. Appleton-Century Co., 1934.

Bone Infections

Here is a book of value not merely for the orthopedic surgeon but for the general practitioner and the student of pathology as well. After years of practical experience in clinical and laboratory work and much delving into contemporary and historical literature, Dr. Wilensky has prepared a general and thoroughgoing monograph upon the subject. No one interested in the field can afford to overlook this work.

Although the introduction is unnecessarily pedantic it is a part of a well planned historical approach. The early chapters build a broad background of normal anatomy and physiology upon which foundation the pathogenesis and symptomology of osteomyelitis are developed. Considerable space is devoted to treatment. In this respect the author has, without bias, quoted freely from many sources giving varied points of view in addition to his own and citing numerous case experiences to advantage.

The book is very comprehensive and written in a clear, scholarly style. It is adequately illustrated with diagrams, normal photographs, X-ray photographs and microphotographs and contains an abundance of tabulated data. Other outstanding features are the inclusion of an extensive bibliography covering all phases of the subject classified and distributed by chapters and author and subject indexes.—D. F. M.

Osteomyelitis—Its Pathogenesis, Symptomology and Treatment, by A. O. Wilensky. xxxii+454 pages. New York, The Macmillan Company, 1934. $9.00.

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